Processing pronouns with real-world referents: An electrophysiological investigation

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Abstract

Investigations of coreferential processing typically require participants to link anaphors with semantically underspecified (“empty”) discourse entities. However, outside the laboratory, anaphors often refer to people, objects, or events about which we possess extensive background knowledge. In addition, recent evidence indicates that comprehenders experience processing difficulty when sentence characters are semantically similar. In the current study we examined whether activating pre-existing real-world knowledge about antecedents influenced coreferential processing in a developing sentence context. Event-related potentials were recorded as participants read sentences containing ambiguous pronouns. Antecedents were either “empty” or were real, well-known individuals. In addition, pronouns either matched or mismatched the sex of their antecedents. Mismatching anaphors elicited a P600 effect whose amplitude was significantly greater when sentence characters were real. Moreover, matching pronouns elicited a P600-like effect when their antecedents were semantically “empty”. Our results suggest that the presence of high-quality representations in a discourse model facilitates coreferential processing.

The factors that influence anaphor processing (such as referential ambiguity, subject assignment, gender, syntactic role, number agreement, and implicit causality) have been studied extensively using behavioral methods (for review, see Garnham, 2001), electrophysiological techniques (for review, see Callahan, 2008) and neuroimaging (Almor, Smith, Bonilha, Fridrikkson, & Rorden, 2007; Nieuwland, Petersson, & Van Berkum, 2007). The goal of the current study is to examine a factor that has been largely ignored in previous investigations of coreferential processing: the role of “real-world” reference. To illustrate, consider the processes that accompany comprehension of this sentence:

- (1) Bill handed John some tickets to a concert and he asked for nothing in return.

Comprehenders must establish two character representations in memory: *Bill* and *John*. The relatively simple sentential context provides few dimensions along which these characters’ representations may be differentiated. In this example, Bill and John are “empty names” – proper names denoting entities with no real-world referents – and they are likely to be represented in a comprehender’s mental model as semantically impoverished, largely similar entities. In contrast, consider the kinds of referential representations that might result if a comprehender knew that these sentences were about *Bill Clinton* and *John Travolta*. For most readers (in the United States, at least) these names are uniquely associated with an abundance of information from long-term memory, ranging from details about these individuals’ physical appearance to their professions. At minimum, the mental representations of this particular Bill and this particular John are much richer in semantic detail than would be the case if readers had no prior knowledge about them (see Burgess & Conley, 1999, for a model of how semantic representations of famous and non-famous names might differ).

It is not surprising that the anaphors used in research rarely refer to actual people, objects, or events. Using referentially “empty” proper names in experimental settings offers non-trivial advantages to the researcher. For example, empty names are used to control for variation in meaning and/or plausibility and their homogeneity controls for the kind of referential representation readers are likely to construct. However, there is evidence that the semantic similarity of potential referents can interfere with processing. Gordon and colleagues have demonstrated this using both self-paced reading (Gordon, Hendrick, & Johnson, 2001, 2004; Gordon, Hendrick, & Levine, 2002; also see Fedorenko, Gibson, & Rohde, 2006; Van Dyke & McElree, 2006) and eye tracking (Gordon, Hendrick, Johnson, & Lee, 2006). These studies have examined how the representational similarity of discourse entities affects the processing of subject- and object-extracted relative clauses. Representational similarity (e.g., when two characters were introduced by a pair of proper names, or by a pair of definite descriptions), increases the processing difficulty that is associated with understanding object-extracted clauses relative to subject-extracted ones as reflected in increased reading times and lower rates of comprehension. However, when similarity is reduced (characters introduced by some mixed pairing of proper name, definite description, or pronoun), the object-subject differences are reduced or eliminated. Gordon and colleagues have argued that, under conditions of high representational similarity, the cue-to-target strength of subsequent retrieval cues is reduced, resulting in processing difficulty; that is, readers’ ability to distinguish among largely similar entities in memory is impaired. Findings such as these suggest that an investigation of the potential effect of richer, more fully realized antecedent representations on the processing of subsequent referring expressions is necessary.

Although the processing consequences of real-world reference are unknown, the idea that it may have *some* effect is not altogether unanticipated; indeed, it has long been known that readers retrieve world knowledge from long-term memory during text processing, which is then integrated into the discourse representation. Most models of text comprehension (e.g., Gernsbacher, 1990; Kintsch, 1998; Sanford & Garrod, 1998) suggest that these processes occur online. Of these, only scenario-mapping and focus theory (SMF theory; Sanford & Garrod, 1998) offers a detailed account of how entities are represented and differentiated in a reader's mental model. According to SMF theory, linguistic input is related to background knowledge in memory *before* the ideas (or propositions) in a sentence are derived. It asserts that the discreteness of discourse entities "is a function of how entities are mapped onto background knowledge" (182). Sanford & Garrod adopt Johnson-Laird's (1983) mental models terminology in suggesting that discourse entities accumulate informational "tokens" that are used in text comprehension. For example, in sentence (1), separate tokens for *Bill* and *John* will be established because they are different names and, thus, ought to refer to discrete entities. Each will also receive a token denoting maleness. In addition, SMF theory claims that verbs elicit scenario-based knowledge, inasmuch as verbs "denote quite complex things and serve as frames through which the rest of the sentence can be organized" (163). The verb *handed* in sentence (1) requires an entity in an agentive role (a giver, an asker) and requires some object to be given or taken. In an SMF account, Bill will likely have a token identifying him as the giver, whereas John will have a token identifying him as the receiver. (Although not all "giving" verbs require a receiver (e.g., *donate*), the verb *handed* specifies a recipient role.) No other information from long-term memory passes to Bill or John. When reference is 'empty,' the Bills and Johns that appear in experimental stimuli are shallowly represented: they are empty names, as similar as they are

different. According to SMF theory, the introduction of real-world reference should produce more complex representations than those in empty-reference conditions. These complex representations result from the extensive mapping of entities in the discourse to details in background knowledge.

Crucially, numerous studies show that knowledge about real world entities (people, places, objects, events, etc.) is applied to sentence processing in parallel with other sources of information (Hagoort, Hald, Bastiaansen & Petersson, 2004; Cook & Myers, 2004; Chwilla & Kolk, 2005; Filik & Leuthold, 2008; Hald, Steenbeck-Planting, & Hagoort, 2007). In addition, researchers in fields other than text processing have shown that real-world reference can influence multiple processes. For example, a study by Balas, Cox, and Conwell (2007) showed that real-world familiarity with faces facilitated reaction times across a range of tasks, including matching the identity, gender, and orientation of a target face to a cued one. Balas et al. suggest that their findings might result from qualitative differences in the informational content of participants' face representations, or from shifting neural resources that are normally devoted to feature processing to other aspects of recognition. If real-world reference affects cognitive processes in domains such as face recognition, it is reasonable to ask if it might also affect cognitive processing in language.

The current study used event-related potentials (ERPs) to examine if and when real-world reference – in this case names of famous people – affected coreferential processing of pronouns. ERPs are measures of neuronal activity that are time-locked to experimental “events”; they are obtained from scalp-recorded EEG. The ERP technique provides fine-grained information about the temporal dynamics of language processing, and there are well-known components that appear in the ERP waveform that are sensitive to various aspects of processing. Two of these are

especially relevant in the current study: the N400 and P600. The **N400** is sensitive to semantic processing of the input. This component manifests as a negative shift in the ERP waveform with an onset about 300 ms post-stimulus, peaking approximately at 400 ms post-stimulus, and maximal over centroparietal electrode sites (Kutas & Hillyard, 1980; for review, see Kutas, Van Petten, & Kleunder, 2006). The amplitude of the N400 is reduced when words are easily integrated with preceding words, sentences, or discourse contexts (Van Berkum et al., 1999; Chwilla, Brown, & Hagoort, 1995; Holcomb, 1993). Recent studies have shown that the N400 is also sensitive to how easily a correct anaphor can refer to an antecedent (Camblin, Ledoux, Boudewyn, Gordon & Swaab, 2007; Ledoux, Camblin, Swaab & Gordon, 2006; Ledoux, Gordon, Camblin & Swaab, 2007; Swaab, Camblin & Gordon, 2004). The N400 may also index semantic access/retrieval processes, with smaller amplitudes reflecting facilitated access (e.g., Kutas & Federmeier, 2000, Van Berkum, 2009). The **P600** manifests as a positive shift in the ERP waveform that peaks approximately 600 ms post-stimulus and is maximal over centroparietal electrode sites. The P600 effect commonly results from syntactic violations (see Hagoort, Brown, & Osterhout, 1999, and Kutas et al., 2006, for review), from violations of syntactic preferences (e.g., garden-path sentences; Osterhout, Holcomb, & Swinney, 1994), or from sentences with legal syntactic structures but anomalous semantic information (Kim & Osterhout, 2005; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003; Nakano, Saron & Swaab, 2010; Vissers, Chwilla, & Kolk, 2007; van Herten, Chwilla, & Kolk, 2006; van de Meerendonk, Kolk, Vissers, & Chwilla 2010). This effect has also been observed when pronouns do not match the stereotypical biological sex of a preceding name (Osterhout, Bersick, & McLaughlin, 1997; Osterhout & Mobley, 1995; Nieuwland & Van Berkum, 2006; Van Berkum et al., 2007),

In the current study, participants read sentences containing pronominal anaphors (either “he” or “she”). Such anaphors contain important semantic information about the biological sex of their referents. The relation between pronouns and their antecedents was manipulated by varying semantic congruence. Congruent pronouns were those that matched the stereotypical biological sex of their antecedent names; incongruent pronouns were those that mismatched the sex of their antecedents. In order to investigate the influence of “real-world” reference, the pronouns’ antecedents were fictional (corresponding to “empty reference”) or well known, famous people. Examples of the experimental stimuli can be seen in Table 1.

Insert Table 1 About Here

Consistent with previous studies, we expected pronouns that were incongruent with the sex of their antecedents to elicit a P600 effect, and that this should occur in both the real-world and empty-reference conditions. Moreover, the P600 effect might be larger in the real-world than empty reference condition. Evidence for this possibility comes from Hammer, Jansma, Lamers, & Münte (2005; see also Hammer, Goebel, Schwarzbach, Münte, & Jansma, 2007; and Hammer, Jansma, Lamers, & Münte, 2008), who capitalized on the fact that pronoun use in German relies on both semantic (biological sex: male or female) and syntactic (gender: male, female, or neuter) information. They examined pronouns that referred either to persons or inanimate objects; therefore, referentially unacceptable person pronouns violated two sources of constraint, whereas referentially unacceptable object pronouns only violated one, since objects do not have a biological sex. Both violations elicited P600 effects; however, the P600 effect was larger in the person than in the object condition. Hammer et al. concluded that the P600 effect is sensitive to

semantic information, a conclusion that fits nicely with studies that report semantic P600 effects (although in these studies the P600 effect is frequently not interpreted as “semantic” per se; alternative interpretations of this effect’s functional significance will follow in the Discussion). Although English, unlike German, does not have inanimate pronouns that are marked for gender, real-world reference is a potential source of important semantic information. Violations may lead to differences in the amplitude of the P600 in the real and empty-reference conditions, viz. a larger P600 effect to incongruent pronouns with real-world antecedents relative to pronouns in empty reference conditions.

In all of our experimental materials, the pronoun was not completely disambiguated until (near) the end of the sentence. Previous research suggests that, in the absence of information indicating an ambiguous pronoun’s referent (e.g., number, gender, implicit causality, etc.), referential assignment is delayed, and effects tend to manifest close to the final words of sentences (Gernsbacher, 1989; Green, McKoon, & Ratcliff, 1992; MacDonald & MacWhinney, 1990). In addition, previous ERP studies have shown N400 effects to sentence-final words that are preceded by a syntactic violation, and this has been attributed to the effects of sentence “wrap-up” (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992, 1993; Osterhout & Nicol, 1999; Hagoort, 2003). This suggests that the sentence final words in the current study should show a reduction in the amplitude of the N400 when referential processing in the preceding context was relatively easy compared to when it was more difficult. The prediction of a downstream effect following an incongruent pronoun is straightforward. When a pronoun does not match either of the potential referents, resolution and integration should be impaired. Therefore, the final words of sentences with incongruent pronouns should elicit an N400 effect relative to the final words of sentences in which a matching pronoun allows for successful

resolution and integration. This prediction should be true regardless of whether the pronouns' referents are real or empty. In addition, it is also possible that pronouns that correctly refer to semantically rich antecedents will facilitate subsequent integration, resulting in a qualitatively more coherent, better-integrated discourse representation. In this case, an N400 effect may result to final words from sentences containing pronouns with semantically "empty" referents, relative to those with real-word reference.

Method

Participants. Twenty undergraduates (11 females) at the University of California, Davis, participated for course credit. All had normal or corrected-to-normal vision, were unmedicated, were neurologically unimpaired, and were right-handed, native English speakers. Participants gave informed consent prior to the experiment.

Materials. Stimuli included an introductory statement that established real or empty reference for characters in a subsequent target sentence (see Table 1). In order to ensure that the real referents were likely to activate a rich, relatively detailed memory representation, normative data were collected. 120 students at the University of California, Davis, who did not participate in the main experiment, were asked to complete a name recognition survey. They received approximately 1,000 names of well-known people from a variety of areas (film, television, politics, science, music, history, and other newsworthy domains). Participants were asked to rate each person on a 1 – 7 recognizability scale; a rating of '7' corresponded to 'very familiar- I am certain I know this person and have knowledge about them', and a rating of '1' corresponded to 'not at all

familiar’ - I don’t know who the person is and know nothing about them’. Only names with an average recognition rating of 5 or higher were used in this experiment.

Target sentences included 160 experimental sentences (of which 64 were adapted from Gernsbacher, 1989) and 80 filler sentences. All were two-clause sentences in which two characters were mentioned in the first clause, one of which was pronominally referenced in the second (see Table 1). The names in each sentence were stereotypically unambiguous as to gender. Within each sentence, characters had the same gender; across all stimuli, half were male and half female. The conjunction “and” was used to connect the clauses. This was done to control for any information that might be inferred from conjunctions such as “but”, “when”, “after”, etc, that readers could use to make predictions about the content of the second clause. Filler sentences followed the same format as experimental sentences, but contained either a repeated name or a plural (*they*) anaphor. Each target sentence was followed by a two-alternative WHO comprehension question, in which the possible answers were the two characters mentioned in the sentences. Half of the questions were about the sentences’ first clause and half about the second; the answers always included one of the two character names from the target sentence. The type of anaphor in each sentence determined the nature of the comprehension question. If the anaphor was an acceptable, congruent pronoun, then the question pertained to the second clause. Since half of the pronouns in the experimental sentences referred to the first-mentioned character and half referred to the second character, this allowed us to assess whether participants understood which characters were the pronouns’ antecedents. If the anaphor was incongruent (mismatching with the biological sex of the potential referents), then the question was about the first clause; of these, half concerned the first-mentioned character and half were about the second character. Average comprehension accuracy was 89.5%.

Four counterbalanced lists were created. In the first list, 40 experimental sentences were pseudorandomly assigned to each of the four conditions (empty/congruent pronoun, empty/incongruent pronoun, real/congruent pronoun, real/incongruent pronoun). Condition assignment in List 1 determined the assignment of sentences to experimental conditions for the remaining lists. For example, a sentence appearing in the empty/congruent condition in List 1 appeared in the empty/incongruent condition in List 2, the real/congruent condition in List 3, the real/incongruent condition in List 4, and so on. Each of the four lists was then separately randomized. All lists contained eight blocks of 30 sentences: 10 filler items and five items from each of the experimental conditions. Each block began with three “warm-up” filler sentences.

Procedure. Participants were tested individually in a dimly lit, electrically shielded sound-attenuating room. They were seated approximately 100 centimeters from the computer screen. To avoid subject-induced artifacts on the EEG signal, participants were instructed to limit their movements as much as possible and to silently read the sentences presented on the screen for comprehension. They were also asked to keep their eyes fixated and to refrain from blinking from the onset of the fixation cross and throughout the presentation of the sentences. Participants were instructed to read the sentences for comprehension. Participants responded to the comprehension questions by pressing a button on a handheld keypad.

Each trial began with an introductory screen identifying sentence characters as either real or empty (e.g., ‘FAMOUS: Bill Clinton and John Travolta’ or ‘FICTIONAL: Bill Smith and John Jones’). Participants indicated that they had read the introduction and were ready to proceed to the sentence by pressing a button on the handheld keypad. Sentence presentation then began with a fixation cross appearing the center of the screen for 1000 ms. The cross alerted

participants to the beginning of each sentence and indicated where they should fixate during sentence presentation. Sentences were presented using a variable serial visual presentation (VSVP) procedure, following the parameters adopted by Van Berkum et al. (2007). This procedure was used because it mimics the variable fixation duration that readers use during normal text presentation, which allows for a more natural reading experience when words are presented one word at the time. All non-critical word presentation durations varied according to the following formula: $187 \text{ ms} + 27 \text{ ms/letter}$ (with 10 letters the limit, yielding a maximum presentation of 457 ms). ISI was 106 ms. First- and second-mentioned names, critical pronouns, and all words following the pronouns were presented for a fixed duration of 300 ms. All words were presented in white, 24-point Tahoma font. The first word of each sentence and all names were capitalized; sentence-final words were presented with a period. Comprehension questions appeared 1000 ms after the sentence-final words and participants were told that they could blink and move their eyes while responding. After participants answered the comprehension question, the prompt “press for next” appeared on the screen. Participants started the next trial by pressing any button on the handheld keypad. Participants were given a short break between each of the eight experimental blocks.

EEG Recording. The electroencephalogram was recorded from 29 electrodes mounted in an elastic cap, referenced to the right mastoid. The EEG recording was re-referenced off-line to an average of the left and right mastoids. Electrodes placed beneath the left eye and at the outer canthi were used to record potential eye movements and blinks. Impedances were kept below 5 k Ω . All single-trial waveforms were screened offline for amplifier blocking, drift, muscle artifacts, eye movements, and blinks; trials containing artifacts were not included in the average

ERPs or in the statistical analyses. 18.66 % of trials were rejected due to artifacts. The EEG signal was band-pass filtered between 0.01 and 30 Hz and sampled at 250 Hz.

Data analysis

Event-related potentials. ERPs were time-locked to pronouns and sentence-final words. These data were analyzed using repeated measures analyses of variance (ANOVAs) performed on the mean amplitude of the ERPs relative to a 100 ms pre-stimulus baseline over all 29 electrode sites. Significant interactions were tested with subsequent contrasts. The Greenhouse–Geisser correction was used to examine effects with more than one degree of freedom in the numerator (Greenhouse & Geisser, 1959). ANOVAs were performed including the factors *reference* (real, empty), *pronoun congruence* (congruent, incongruent) and *electrode site* (29 sites). The critical time window for the anaphors was 500-800ms to capture P600 effects, and for the final words the 300-500 ms time window was analyzed to capture the N400 effect.

Results

Anaphors. Grand average ERPs to the critical pronouns are shown in Figures 1 and 2. The omnibus ANOVA for the P600 time window revealed a significant main effect of pronoun congruence, $F(1,19) = 8.04, p = .01$. A significant pronoun congruence x electrode interaction was also observed, $F(28, 532) = 6.22, p < .01$. Visual inspection of the waveforms confirmed that this interaction reflects the typical posterior distribution of the P600 when a pronoun is encountered whose gender is inconsistent with the biological sex of available referents. Critically, the omnibus ANOVA also revealed a significant interaction of reference x pronoun congruence, $F(1, 19) = 7.87, p = .01$.

Insert Figures 1 & 2 About Here

Pairwise Comparisons. In the empty condition, (Figure 1, left), a significant congruence x electrode interaction was observed, $F(128, 532) = 3.11, p < .05$). Follow-up analysis was restricted to centroparietal electrode sites for which the P600 is maximal (CP1/2, CP5/6, P3/4, O1/2, Pz, POz). The analysis revealed a significant effect of pronoun congruence, $F(1, 19) = 6.07, p < .05$., in which the amplitude of the P600 effect was greater to incongruent pronouns relative to congruent pronouns. In the real-world reference condition (Figure 1, right), a significant effect of pronoun congruence, $F(1,19) = 11.50, p < .01$, and a significant pronoun congruence x electrode interaction were also observed, $F(28, 532) = 5.64, p < .01$. Analysis of centroparietal electrodes yielded a main effect of pronoun congruence, $F(1, 19) = 18.29, p < .001$. In the real-world condition, the P600 to the incongruent pronouns was also greater than to the congruent pronouns. In addition, the mean amplitude of the P600 effect in the real world conditions ($3.23 \mu\text{V}$) was numerically greater than in the empty condition ($1.97 \mu\text{V}$). We therefore also analyzed the difference waves to the pronouns. In our analysis, we subtracted the congruent condition from the incongruent condition, in both the empty and the real-world conditions. The difference between the P600 effects in these conditions was significant in the 500-800 ms window, $F(1,19) = 5.60, p < .05$, with real-world reference eliciting a larger P600 effect of pronoun congruence than empty reference (Figure 3).

Insert Figure 3 About Here

When the pronouns were incongruent, significant differences emerged between real and empty conditions, $F(1,19) = 4.83, p < .05$ (Figure 2, right). Incongruent pronouns with empty referents elicited a more positive shift in the EEG than those with real-world referents. These comparisons exhibit hallmarks of the P600 effect in terms of polarity, scalp topography, and timing. In contrast, when the pronouns were congruent, no main effects of real-world/empty reference and no electrode interactions were significant in the “typical” P600 time window, $F(1,19) = 2.11, p = .16$; however, a significant effect of reference does appear in a later time-window (550-700 ms) and is clearly visible in the waveforms, $F(1,19) = 5.00, p < .05$ (Figure 2, left). This effect is the reverse of that observed in the incongruent conditions: here, pronouns with real-world referents elicited a more positive shift than did pronouns with empty referents.

Final words. Grand average ERPs to the final words are shown in Figure 4. The omnibus ANOVA for the N400 time window revealed no significant main effects (pronoun congruence, $F(1,19) = 1.78, p = .20$; reference, $F < 1$). However, we observed a significant reference x pronoun congruence x electrode interaction, $F(1, 19) = 2.61, p < .05$. Analysis of posterior electrodes corresponding to the typical distribution of the N400 effect (C3/4, CP1/2, CP5/6, P3/4, Cz, Pz, and POz) revealed a significant main effect of pronoun congruence, $F(1,19) = 4.96, p < .05$; a pronoun congruence x electrode interaction, $F(1,19) = 3.10, p < .05$; and, crucially, a significant reference x pronoun congruence interaction, $F(1,19) = 7.78, p = .01$. Subsequent contrasts were performed across these electrode sites.

Insert Figure 4 About Here

Pairwise Comparisons. No significant differences emerged between real world and empty conditions for the incongruent pronoun, $F(1,19) = 1.32, p = .26$, or the congruent pronoun, $F(1,19) = 2.44, p = .14$. However, in the empty conditions (Figure 4, left), a significant effect of pronoun congruence was observed, $F(1, 19) = 8.29, p < .01$, and a congruence x electrode interaction was also significant, $F(10, 190) = 2.95, p < .05$. The polarity, scalp topography, and timing of this result are characteristic of the classic N400 effect. In contrast, there was no such N400 effect of pronoun congruence in the real-world reference conditions (all $F_s < 1$; Figure 4, right).

We conducted a difference wave analysis in order to directly examine the difference of pronoun congruence on processing of the final words for empty and real-world condition. While no main effect of reference appeared in the analysis of all 29 electrodes, we observed a significant reference x electrode interaction, $F(1, 19) = 2.76, p < .05$, in the 300-500 ms window. Analysis of posterior electrodes corresponding to the typical distribution of the N400 effect (C3/4, CP1/2, CP5/6, P3/4, Cz, Pz, and POz) revealed a significant negative shift to the final words in empty conditions relative to those in real-reference conditions in the 300-500 ms window, $F(1,19) = 4.73, p < .05$. which can be seen in Figure 5.

Discussion

The results of this experiment show that the availability of real-world information about characters in a sentence modulates anaphor processing. We predicted that the referential violation conditions (Figure 1) would replicate the P600 effects found in previous research for both empty reference and real-world reference conditions. Our results confirmed this prediction. Van Berkum and colleagues (2007) note that in both English and Dutch these violations are

driven by a *semantic* mismatch between the pronoun and the biological gender of its intended referent. Van Berkum asserts that the P600 effect, in these languages, is due to the “grammaticalization” of semantic information – the incorporation of the required biological sex of an anaphor’s antecedent into the pronouns themselves. Other studies have reported semantically-based P600 effects (Kim & Osterhout, 2005; Kuperberg et al., 2003, 2007a, 2007b; Nakano, Saron & Swaab, 2010; Vissers et al., 2007; van Herten, et al., 2006; van de Meerendonk et al., 2010); however, such studies typically involve a disparity between a legal syntactic structure and an anomalous semantic analysis (as in semantic reversal anomalies, e.g., *The cat that fled from the mice ran through the room*, or theme-agent violations, e.g., *For breakfast the eggs would only eat toast and jam*.) Although semantically driven, such circumstances are clearly different from studies of pronoun mismatch (in English and Dutch) in which no alternative interpretation is readily available. The current type of semantic violation has thus been described as a “referentially induced” P600 effect (Van Berkum et al., 2007).

It is of significant note that the amplitude of the “referentially-induced” P600 effect varied as a function of additional semantic information. The difference wave analysis confirmed our hypothesis that the introduction of real-world semantic information about potential antecedents would increase the amplitude of the referential P600 effect. This prediction was based on previous anaphor processing research by Hammer and colleagues (Hammer et al., 2005) in which the violation of syntactic *and* semantic constraints elicited larger P600 amplitudes than did syntactic violations alone, suggesting that multiple streams of information are active in German pronoun resolution. However, the current experiment differs from this study (and others by the same group, e.g., Hammer et al., 2007, 2008), in a critical way: Hammer and colleagues offered evidence that multiple violations resulted in larger P600 effects, whereas

the current experiment shows modulation of P600 amplitude *without* an additional violation. In the current study, the sole violation – mismatch of a pronoun and its potential antecedent’s biological sex – is the same across reference conditions. It is the addition of semantic information from long-term memory into readers’ mental representations that appears to enhance the magnitude of the violation. The figure shows a P600 effect to an incongruent pronoun in the real-world condition relative to the same incongruent pronoun in the empty reference condition.

There are a number of possible explanations for the observed effect of real-world semantic information on the P600 component. Several models of language processing claim that multiple analytic streams interact during comprehension, with conflict between the processing streams producing a P600 effect. For example, Kuperberg (2007) posits a combinatorial account wherein there is at least one semantic memory-based stream contributing information in parallel to analyses of syntactic relations, animacy, and thematic information. According to this account, it may be the case that the addition of real-world semantic information rendered the existing referential violation more salient; thus the enhanced P600 amplitudes reflects a conflict between the strong semantic cue provided by the stereotypical antecedent name (especially in the real-world condition) and the retrieval cue provided by the morphological information contained in the pronouns. Similarly, the incorrect use of reflexives induces P600 effects (Osterhout, Bersick, & McLaughlin, 1997; Osterhout & Mobley, 1995) and these certainly constitute syntactic problems, as they violate Principle A of Chomsky’s Binding Theory (1981; see also: Gordon, Kacirik and Swaab, under review). Alternatively, Hagoort and colleagues have proposed a processing competition account, which also assumes that information from one level of analysis can influence processing at other levels (Hagoort, Baggio, & Wilems, 2009). According to this theory, the relatively stronger semantic cues provided by the real-world information may result

in greater processing costs at the syntactic level, which would manifest as a larger P600 effect. A third possibility is suggested by Burkhardt (2007): the effort that is required to update a reader's discourse model can influence the P600, and greater semantic detail in the model reduces processing costs (and P600 amplitude). Similarly, the empty reference conditions in the current study contained potential antecedents that were also less detailed; congruent pronouns in these conditions elicited a larger P600 effect than did those in real-world reference conditions. However, regardless of these different interpretations, the overall conclusion remains the same: semantics plays a role in linking a pronoun to its antecedent.

We also predicted that sentence-final words following incongruent pronouns would elicit an N400 effect relative to sentence-final words following congruent pronouns. We reasoned that failure to find an appropriate referent at the pronoun is likely to impair subsequent integration processes. Our results confirmed this prediction – but only when the characters in the sentences were empty, i.e., in the empty reference condition (Figure 4). Our anaphor analyses suggest potential explanations for this pattern of results. The P600 effect at the incongruent pronouns differed as a function of reference, with a significantly larger effect evident when candidate antecedents were real. One possibility is that readers processed the mismatch as less critical to comprehension in the empty reference conditions, and as a more serious problem in the real-world conditions. A second possibility is that readers simply abandoned the search for incongruent pronouns' referents earlier in real than in empty reference conditions. In either case, readers may have been more likely to correct the referential error in the real reference conditions, thus enabling subsequent integration processes to proceed normally; this possibility is supported by previous research associating the posterior P600 with syntactic repair operations (Kaan & Swaab, 2003). In contrast, incongruent pronouns with empty referents may not have elicited any

sort of corrective process, resulting in persistent downstream difficulty regardless of later disambiguating information.

Overall, these results are broadly consistent with scenario-mapping and focus theory (Sanford & Garrod, 1998). Although other theories of text processing (e.g., Gernsbacher, 1990; Kintsch, 1998) concede that world knowledge may influence processing prior to deriving sentence ideas (propositions), the way in which this is accomplished is not well specified. SMF theory, in contrast, holds that linguistic input is mapped to relevant background knowledge before or during structure-building operations, and that this knowledge will be used to differentiate among characters that are active in a comprehender's mental model. Responses to the violation conditions in this experiment offer clear support for the notion that previously activated information from long-term memory was used very rapidly during comprehension of the experimental sentences. Additionally, the results show evidence that real world knowledge was used in the referentially congruent condition during pronoun processing as well, although this effect emerged 50ms later than in the incongruent pronoun condition. In Figure 2 (left), a main effect of referential condition is visible, appearing in a later P600 window. In contrast to the findings for the incongruent condition, here the P600 was greater to the congruent pronouns that referred to empty antecedents. A reduction in the P600 to the congruent pronouns in the real world relative to the empty condition suggests that coreferential processing is facilitated very rapidly when more information about the antecedent is available.

Our findings provide new information about how real-world information is used during language processing. Previous studies have focused on how readers are able to detect violations of real-world knowledge (e.g., pragmatic violations, such as *Dutch trains are white and very crowded*, as in Hagoort et al., 2004). The current study instead provides information about how

background information is used during comprehension of both legal and anomalous sentences.

The results suggest that the semantic detail of entities in readers' mental models is important. In our study, such information rendered violations substantially more striking, and affected subsequent integration processes, possibly even compensating for referentially failing pronouns and facilitating integration by the end of the sentence. However, the experimental sentences in the current study described situations that were more or less arbitrary, unrelated to the actual identities of the characters included in them. In addition, the use of inexplicit anaphors such as pronouns may increase the importance of additional semantic detail about potential referents, although more explicit anaphors (such as repeated names, which themselves contain semantic information about their antecedents) may not. Further research is therefore necessary to examine how coreferential processing might be affected by including non-arbitrary content, in which the semantic details of sentence characters – including, perhaps, the plausibility of their role and/or actions in a given situation – are relevant to comprehension.

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Table 1. Example of Introductions and Target Sentences

“EMPTY” REFERENCE (MALE)

FICTIONAL: Bill Smith and John Jones.

“REAL WORLD” REFERENCE (MALE)

FAMOUS: Bill Clinton and John Travolta.

Referentially Acceptable:

Bill handed John some tickets to a concert and *he* asked for nothing in return.

Referentially Unacceptable:

Bill handed John some tickets to a concert and *she* asked for nothing in return.

“EMPTY” REFERENCE (FEMALE)

FICTIONAL: Julia Harris and Britney Warner

“REAL WORLD” REFERENCE (FEMALE)

FAMOUS: Julia Roberts and Britney Spears

Referentially Acceptable:

Julia saved Britney from drowning in the creek and *she* quickly became a local hero.

Referentially Unacceptable:

Julia saved Britney from drowning in the creek and *he* quickly became a local hero.

Note: critical anaphors are italicized and antecedents are boldfaced, but were presented to participants in normal font.

Figure 1. Grand average ERPs (n=20) at Fz, Cz and Pz for the critical pronouns in empty and real-world reference conditions. Incongruent pronouns show an enhanced positivity compared with congruent pronouns. The topographic maps show the difference between incongruent and congruent pronouns in the 500-800ms time window. The arrows point to the P600 region on electrode Pz.

Congruence Effects: Pronouns

Figure 2. Grand average ERPs (n=20) at Fz, Cz and Pz for the critical pronouns that were congruent or incongruent with their antecedents for the real world and the empty referent conditions. The congruent pronouns show a greater P600 in the real-world than in the empty conditions, for the incongruent pronouns this is reversed. The arrows point to the P600 region on electrode Pz.

Reference Effects: Pronouns

Figure 3. Difference waves at Fz, Cz and Pz electrode sites show the difference between the real and empty reference conditions at critical pronouns in the incongruent condition. When pronouns have real-world antecedents, the effect of pronoun incongruence is significantly more positive than that observed when potential referents are referentially “empty”. The arrow points to the P600 region on electrode Pz.

Congruence Difference Wave (Pronouns)

Figure 4. Grand average ERPs at Fz, Cz and Pz for the sentence final words that followed critical pronouns that were congruent or incongruent with the antecedents. In the empty reference conditions, an N400 effect is observed to the final words as a function of whether or not a preceding pronoun was congruent with its antecedent. In real-reference conditions, no such N400 effect is visible. The arrows point to the N400 region on electrode Pz.