THE NEUROPHYSIOLOGY OF SCOPE AMBIGUITY[*]

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1. Introduction

The goal of the present study was to investigate the initial interpretation of sentences such as “Every kid climbed a tree” in order to further our understanding of how such scope ambiguities are processed in real-time. Specifically, the interpretation of such sentences was disambiguated with the use of continuation sentences that began with either a plural noun phrase (NP), as in “The trees were in the park” or a singular NP “The tree was in the park”. In this way, each continuation sentence corresponded to a different scope possibility, where the plural marking was consistent with a surface scope reading and the singular marking corresponded to the inverse scope reading.

This design was built upon the first published study to investigate scope ambiguity using behavioural measures by Kurtzman & MacDonald (1993). That work sought to investigate a number of different factors that might affect the interpretation of sentences exhibiting scope ambiguity, and as such included 4 experiments. Experiment 1 investigated precisely the quantifiers of interest, namely “every” and “a”. Participants read sentences in their entirety containing quantifier noun phrases (NPs) such as *”<u>Every kid</u> climbed <u>a tree</u>”* which were then followed by another possible sentence, either “*The trees were full of apples”* or “*The tree was full of apples”*. These sentences were also presented as a whole. At the end of either continuation sentence, participants were asked to judge whether it formed a good continuation of the first (ambiguous) context sentence or not. In addition, the experiment included unambiguous control context sentences such as “*Every kid climbed a different tree. The trees were…”* and “*Every kid climbed the same tree. The tree was…”* One of the many findings of that seminal work was that, overall, participants preferred a plural continuation for ambiguous sentences of the form “*Every kid climbed a tree” (*77% of the time; the corresponding plural and singular continuations that followed the unambiguous control contexts were judged at rates of approximately 85% each (see also Kemtes & Kemper, 1999).

We decided to further investigate interpretation at the syntax-semantics interface by building on the findings of Kurtzman and MacDonald (1993) regarding scope ambiguity. Whereas their results regarding the preferred interpretation are clear, (and expected on theoretical grounds, see Dwivedi, 1996) we note that conscious judgments were measured at the end of the continuation sentences. Although such judgments are useful as a guiding measure to understanding the processing of such sentences, this method has two drawbacks—first, it calls upon a meta-linguistic assessment of the stimuli and as such is not reflective of unconscious processing, which is arguably our goal in understanding language processing. Second, these judgments were taken only

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[*] Thanks to Matt Goldhawk for help in preparing the manuscript.

Actes du congrès annuel de l’Association canadienne de linguistique 2008.
Proceedings of the 2008 annual conference of the Canadian Linguistic Association.

after the entire sentence had been read; in other words, it's unclear whether there were earlier decisions regarding parsing that were entertained and then discarded, or whether the ultimate judgement made was the only grammatical choice considered. In addition, in that study, reaction time measures were not included at all. Furthermore, whereas more recent behavioural findings by Tunstall (1998) and Anderson (2004) support the notion that an immediate preference for surface scope is made very early on in self-paced sentence reading studies, eye-tracking studies by Filik and colleagues (Filik, Paterson, & Liversedge, 2004; Paterson, Filik, & Liversedge, 2006) are equivocal regarding the status of the surface scope assignment. One potential reason why the above-mentioned studies are difficult to interpret is because they examined several linguistic factors simultaneously—e.g., type of verb phrase, type of verb, type of quantifier, order of quantifiers.

The present work seeks to address these issues in the following way: first, conscious judgments regarding the sentences in question were not required; in this way we hoped to understand the natural processing of such stimuli. The design of the stimuli was limited to one syntactic structure, using a specific order of two quantifiers, as well as using a particular kind of verb (see below). We hope that this more constrained design will yield to more interpretable findings. Furthermore, our goal was to chart the time-course of interpretation in the second disambiguating sentence, using the exquisite time resolution afforded by event-related brain potentials (ERPs). ERPs reflect voltage changes in the electrical brain activity associated with cognitive processing. This methodology is particularly useful for our purposes because it allows us to examine the processing of naturalistic language stimuli on-line with very high temporal resolution (on the order of milliseconds) and adequate spatial resolution (through scalp distribution). More importantly, there are several ERP components (reviewed below) that are thought to be specifically associated with distinct aspects of lexical-semantic and syntactic processing. Thus, the nature of the ERP component elicited might provide a qualitative understanding of the nature of the linguistic processing undertaken—that is, whether semantic, syntactic or other processing mechanisms are recruited during the comprehension of the stimuli.

For example, if we assume the conclusions found in Kurtzman and MacDonald (1993), that is, that the brain selects a particular interpretation, namely, the surface scope reading, then it should be the case that a continuation sentence that does not match that interpretation would be dispreferred and/or exhibit linguistic anomaly. Since the logical interpretation of sentences occurs at the syntax-semantics interface, we might expect ERP components that are reflective of semantic, syntactic, or both processes. We review the nature of these components below.

With regard to semantic processing, since the classic work of Kutas & Hillyard (1980, 1983), it has been shown that a semantically anomalous or unexpected word, (e.g., *He spread the warm bread with* ***socks***) elicits a large N400 effect, a distinct negative shift in the ERP waveform that begins about 200 msec after the onset of the critical word and peaks at about 400 msec post-stimulus. This is in contrast to semantically acceptable or expected words (e.g., *He spread the warm bread with* **butter**) where the amplitude of the N400 is significantly smaller. St. George et al. (1997) have demonstrated that, in addition to sentence-internal semantic information, N400 amplitude is sensitive to contextual constraints across discourse.

In contrast, the P600 is a later-occurring ERP component traditionally thought to be elicited by structural aspects of the linguistic input **(**Hagoort et al., 1993). This component has been related to the processes of revision and repair in sentence processing. Recent work by Kaan et al. (2000) indicates that the P600 may be a measure of syntactic integration, where constructions that are more difficult to integrate produce larger P600 amplitudes. Kaan and Swaab (2003a,b) argue that the P600 actually represents a family of components distributed across the scalp. P600 activity with a posterior distribution appears to index syntactic processing difficulty, whereas P600 activity with a frontal distribution is related to ambiguity resolution and/or an increase in discourse level complexity. That is, frontal P600 activity has been claimed to signal that a preferred structural analysis can no longer be maintained and must be revised. In Dwivedi, Phillips, Laguë-Beauvais and Baum (2006), we found such a waveform in response to continuation sentences that were inconsistent with quantificational mood as defined in the previous context sentence. We interpreted this finding as reflecting the cognitive process of revision of previous linguistic semantic structure.

If we extend this interpretation to the current experiment, then we would predict the following: if the findings of Kurtzman and MacDonald (1993) are correct that the preferred interpretation of “Every kid climbed a tree” is the plural interpretation (corresponding to surface scope), then the singular interpretation “The tree was in the park” is the non-preferred reading. As such, when the singular follows such a context sentence, a revision of the first-pass interpretation (i.e., plural preferred) would need to occur at the earliest possible point in the sentence, which would be at “tree”. Furthermore, the neurophysiological form of the empirical difference should be a frontal P600 effect, which would replicate our previous findings. Another possibility is that the N400 would be elicited, which would reflect the semantic nature of the computation.

Note that the predictions above are based on findings of Kurtzman and MacDonald (1993) who measured interpretive preferences at the end of sentences. As such, it is unclear what is happening earlier during the ongoing processing of these sentences. For example, given the complexity of the linguistic material in sentences such as “Every kid climbed a tree”, one might hypothesize that the brain/parser waits to assign scope meaning. This might be especially the case, given that these sentences are presented without any preceding context; that is, the quantifiers are not given an explicit restriction over which to quantify (cf. Westerståhl, 1985; von Fintel, 1994). In the sentence “Every kid climbed a tree”, it is unclear whether it is every kid at a birthday party, at the park, or outside in my backyard. It could be the case that in the absence of contextual information which could help clarify the scenario, the brain/parser waits to assign meaning. If this were the case, then scope would be left uninterpreted for such sentences, which would translate into an ambiguous context—there would be no immediate preferred reading. If we think about how “the tree(s)” would be integrated into such a context, then yet another

ERP waveform would be predicted, which has been recently labeled the **Nref.** For example, van Berkum, Brown and Hagoort (1999a) and van Berkum, Brown, Hagoort & Zwitserlood (2003) have examined the question of referential ambiguity using ERPs in the visual and auditory modalities, respectively. Those studies set up (Dutch) discourses where either there was one referent or two possible referents to a later-occurring anaphoric Noun Phrase (NP). For example, for the anaphoric NP <u>*the girl*</u>, a previous discourse context would posit either two girls or just one girl and a boy. They found that for target sentences that had the anaphoric NP "*David told <u>the girl</u>…*" at the critical word *girl*, a slow negative shift emerged just 280 ms after the noun for discourses that posited two possible antecedent girls vs. those that had just one. Van Berkum et al. (1999a, 2003) interpreted these results in the following way: first, the slow negative shift is interpreted as a marker of increased cognitive load associated with ambiguity in the interpretation of the noun "girl". That is, slow negative shifts have been associated with increased use of working memory resources, as argued by Kluender and Kutas (1993) and others (Münte, Schiltz, and Kutas, 1998; Hammer, Jansma, Lamers, and Munte, 2005). Thus, van Berkum et al. claim that the possibility of there being two candidate referents for the NP *the girl* is translated into the cost of either maintaining the two previously mentioned NPs in memory, or the increased search requirements for resolving the reference of *the girl*.

For the purposes of the current study, if scope is not assigned immediately in the context sentence, then the reference of "the tree(s)" in the continuation sentence would indeed be ambiguous, and a slow negative shift would be predicted.

In sum, this study seeks to answer at least the following two questions: First, what is the neurophysiological signature associated with integrating an NP into a context that is defined by scope ambiguity, and how can that inform a theory of processing such sentences? Furthermore, what is the time course of this process, that is, where in the sentence does integration begin to occur with the previous context?

We addressed the foregoing questions in the following way: as briefly aforementioned, we created two-sentence discourses where the first (context) sentence displayed quantifier scope ambiguity because the subject NP contained the quantifier "*every*" and the inanimate object NP contained the existential quantifier "*a*". The interpretation of the context sentence was disambiguated in the second (continuation) sentence in the following way: the subject NP of the continuation sentence was anaphoric to the object of the context sentence, and it was marked as either singular or plural (note again that the plural reading is consistent with the surface scope reading whereas the singular marking corresponds to the inverse scope reading of the sentence). A control condition was constructed in order to ensure that the effects obtained were indeed due to context, and not the fact that two different kinds of nouns, that is, plural vs. singular, are being compared. Thus, each continuation sentence—both those with plural vs. singular nouns and verbs-- was preceded by two different kinds of contexts: Ambiguous and Control. Table 1 lists the 4 conditions explicitly.

Table 1

Experimental sample stimuli

		Context	
		Ambiguous	Unambiguous
Number	Plural	Every kid climbed a tree. The trees were in the park.	Every kid climbed a different tree. The trees were in the park.
	Singular	Every kid climbed a tree. The tree was in the park.	Every kid climbed the same tree. The tree was in the park.

If the findings of Kurtzman and MacDonald (1993) are on track, then the preferred interpretation of the ambiguous context sentence should be the plural continuation sentence. Thus, there should be no empirical difference between this condition (Ambiguous-Plural) and the Control-Plural condition. Given that the singular condition is hypothesized to be the non-preferred condition, then the Ambiguous-Singular condition should differ empirically from the Control-Singular condition as there was no ambiguity in the context of this latter condition. If this is correct, then perceivers will be forced to revise their interpretation when faced with the singular continuation of the scope ambiguous context. Furthermore, we predict, along the lines of Dwivedi et al. (2006), that the neurophysiological form of this cognitive revision would be frontal positivity. In addition, the revision should occur as soon as possible, which would be at the noun position. On the other hand, if perceivers wait to assign reference in an ambiguous context, then we would predict that Ambiguous-Plural and Ambiguous-Singular conditions should pattern together in comparison with their controls and the form of the waveform elicited would be a sustained, negative-going waveform, the Nref. In addition, the timing of this waveform would also be as early as possible, that is at the Noun position “tree(s)”.

2. Methods

2.1 Participants

25 native speakers of English (15 female, mean age 21.85 years, range 18 to 27 years) were recruited at Concordia University and were either paid for their participation or received partial course credit. All subjects had normal or corrected-to-normal vision and were right handed, as assessed by the Handedness Inventory (Briggs & Nebes, 1975). None of the participants reported any neurological impairments, history of neurological trauma or use of neuroleptics. Also, none of them had participated in the pilot ratings task (see below)

2.2 Materials

Ambiguous Context Sentences Simple declarative (e.g., subject^verb^object) context sentences were constructed where the subject was a quantified NP, which was always the universal quantifier *every* paired with an animate head noun (e.g., *kid, tourist, shopper*), followed by an action verb in the past tense (e.g., *climbed, visited, squeezed*), followed by an inanimate object NP (e.g., *tree, statue, melon*) paired with the existential quantifier "a", resulting in sentences such as *Every kid climbed a tree, Every tourist visited a statue, Every shopper squeezed a melon.* Despite the syntactic simplicity of these sentences, and the fact that the object NP is marked as morphologically singular, the meaning of these sentences is ambiguous, due to the scope interaction of the quantified subject and the indefinite object, as discussed in the introduction.

Control Context Sentences: In contrast, the Control context sentences distinguished the interpretation of the indefinite objects as unambiguously singular or plural. The structure of the sentences was exactly the same as the ambiguous context sentences (e.g., subject^verb^object) except that the direct object was preceded by different adjectives. Thus, instead of the ambiguous *Every kid climbed a tree*, we adopted the markers used by Kurtzman and MacDonald (1993), where the Control Singular context condition was of the form *Every kid climbed the same tree*, and the Control Plural context condition was *Every kid climbed a different tree*. The Control Singular (CS) context sentence was always followed by the singular continuation sentence, whereas the Control Plural (CP) context condition was always followed by the plural continuation sentence. This resulted in the following two control conditions: CS: *Every kid climbed the same tree. The tree was in the park*; and CP: *Every kid climbed a different tree*. *The trees were in the park.*

Continuation Sentences: The form of the experimental continuation sentences was the following: the subject NP always referred back to the object NP of the context sentence. Furthermore, the subject was either plural or singular (e.g., *trees* vs. *tree*) and was followed by an auxiliary verb (e.g., *were* or *was*) and then a predicate. Half of the time the predicate was a prepositional phrase (e.g., *The tree(s)were/was* ***in the park***), and the other half, it was an adjectival phrase (e.g., *The melon(s) were/was* ***large and green***).

Thus, the factors of interest were Ambiguity of the context sentence (ambiguous vs. unambiguous/control) and Number in the continuation sentences (Plural or Singular), yielding four conditions: Ambiguous Singular (AS), Control Singular (CS), Ambiguous Plural (AP), Control Plural (CP).

160 scenarios were created (e.g., *kid^climb^tree; shopper^squeeze^melon; tourist^visit^statue*) for each of the four conditions (Ambiguous-Plural, Control-Plural, Ambiguous-Singular, Control-Singular) resulting in a total of 640 sentence pairs. In order to reduce repetition effects, the stimuli were divided into four counterbalanced lists, such that each participant saw an equal number of sentence pairs from each condition, resulting in 40 trials per experimental condition per list.

Filler sentence pairs: In addition to the experimental discourses, there were 160 filler discourses to reduce the predictability of the experimental stimuli and to reduce the chance of participants adopting particular reading strategies. Furthermore, since the predicted waveform for the non-preferred reading could be of different varieties, these fillers were constructed to ensure that the participants were in fact capable of producing ERP effects such as the N400 and the P600 in response to more classic semantic and syntactic ambiguity manipulations, respectively. These filler sentences were of the following type:

Filler Anaphoric--Anaphora to Non-Object NP Antecedent : 40 of the 160 filler discourses were coherent discourses, meaning that they were both semantically and syntactically correct. These consisted of sentences where the subject of the continuation sentence referred back to an NP which was not an object, since in the critical sentences anaphora was always to the object NP. The form of the antecedent NP varied from bare plurals, to quantified NPs (excluding "*every*") to indefinite NPs. Furthermore, the form of the continuation sentence was either a singular or plural definite NP, or a singular pronoun such as *it* or a plural pronoun such as *they.* These 40 coherent fillers were immediately followed by forced-choice comprehension questions, in order to ensure that subjects paid attention to the stimuli.[1] When the questions were presented after these stimuli, the two alternative answers were shown on the left- and right-hand sides of the computer screen, and participants had to press the corresponding button on a response pad to indicate the correct answer. The position of the correct answer was counterbalanced across trials. Samples of fillers appear below:

Filler (1) *On afternoons, Alice went to the babysitter.*
The afternoons were a time to relax after school.
Question: The afternoons were a time to relax after what ?
Answer: SCHOOL WORK

Incoherent N400 Fillers: 40 filler sentences used auxiliaries not used in the target sentences (e.g., *could, can, ought to, did, will*) and were anomalous, but for reasons independent of grammatical constraints across sentences. Instead, these represented violations of real-world knowledge.

Syntactically incoherent fillers: 80 fillers consisted of typical P600 violations, where there was a number agreement violation in the continuation sentence.

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[1] Questions about the Filler Anomalous sentences were not used, since the sentences did not make sense, and questions about the experimental sentences were not used in order to avoid encouraging any specific strategies for reading such sentences.

Half the time the violation occurred where the subject was plural and the auxiliary verb was singular, and the other half of the time, the violation resulted because the subject was singular and the auxiliary verb was plural. Furthermore, the context sentence always contained a quantified NP, which allowed for either a plural or singular subject in the continuation sentence e.g., *few N, most N, many N, all N, no N, a N.*

In order to reduce repetition, 160 grammatical/ungrammatical stimuli were created in total, with 80 grammatical and 80 correspondingly ungrammatical stimuli. These were distributed among the 4 counterbalanced lists as described below; that is, the stimuli were divided in half, such that two of the 4 lists had 40 grammatical and 40 ungrammatical stimuli, where there was no repetition between lists. This was a very effective distractor method; in debriefing sessions post-experiment, participants often felt that the point of the experiment was to understand number (dis)agreement. Thus, we feel confident that participants were naïve as to the purpose of the experiment. In total, each list viewed by a participant contained 320 sentence pairs: 160 target stimuli (40 from each from AS, AP, CS, CP) and 160 filler sentence pairs as described above. As noted earlier, each participant saw one list only, with sentences presented in a pseudo-random fixed sequence with the stipulation that no two trials from the same experimental condition or filler condition followed each other.

2.3 Pretests

We evaluated the acceptability of a subset (n=160) of the ambiguous context sentences in an off-line norming study. Two semi-randomized lists were created and 32 subjects recruited at McGill University were paid $10 for their participation. None of these subjects participated in the on-line ERP experiment. In this off-line task, discourses were presented in a booklet in a pseudo-random order, with the constraint that no more than two of the same type of trial succeeded one another. 80 ambiguous context sentences were presented, as well as 80 unambiguous ones (40 Control Singular and 40 Control Plural). In addition, 80 fillers were used from an unrelated experiment. The participants were asked to circle the continuation sentence that fit better with the first sentence. Note that plural and singular continuations were counterbalanced to appear either on the top or bottom. Overall, our results were consistent with those of Kurtzman and MacDonald (1993); the preferred interpretation for Ambiguous sentences (e.g., *Every kid climbed a tree*) was indeed the plural reading—73% (vs. 77% Kurtzman and MacDonald, 1993). As expected, pair-wise comparisons (both by participants and by items) revealed that this differed significantly from the control conditions. That is, Ambiguous sentences judged as plural differed significantly from the Control Plural condition, which was judged as plural 95% of the time, with very little variability ($p< .001$), as well as from Control Singular, which was judged as singular 85% of the time ($p< .001$).

Unlike the findings of Kurtzman and MacDonald, however, the CS and CP conditions in our study differed significantly *from each other* ($p< .001$). Given that these were supposed to represent ceiling scores, this was an unexpected finding. We will see below in the ERP results that these off-line results foreshadow our on-line findings.

2.4 Procedure

For the experimental test, participants were tested individually in one session, which lasted approximately 3 hours. Short breaks were given when required. Following the application of the EEG electrodes, subjects were seated in front of a computer screen approximately one meter away. All stimuli were presented in white text on a black background in 26 point Arial font on a Compaq Deskpro computer, with a Compaq V74 16” monitor using STIM presentation software (Compumedics Neuroscan USA, Inc., El Paso, TX, USA). The words of the continuation sentence were presented between 0.014 and 0.089 degrees of visual angle in the center of the computer monitor. Participants responded to the questions by using a Stim System Response Pad (Compumedics Neuroscan USA, Inc., El Paso, TX, USA).

Each context sentence (S1) was presented in its entirety; participants pressed a button to indicate when they were ready for the continuation sentence (S2). Following an ISI of 600 ms, the continuation sentence was presented one-word-at-a-time in the centre of the screen with each word presented for 300 ms followed by an ISI of 300 ms. This presentation rate minimized eye movement artifacts in the EEG recordings and allowed for time-locking the EEG recording to the presentation of each word. Between each sentence pair there was a 3 second delay to make sure the participants read the sentences as distinct pairs. Participants were instructed to silently read the context sentence, to press a button when it had been read, and to read each individual word of the subsequent sentence. Participants were instructed not to speak, move, or blink their eyes during the presentation of the stimuli. Practice trials were included to accustom participants to the task. When required, participants responded to a comprehension question using a hand held pad. This question appeared 100 ms after the last word of certain sentence pairs, and only occurred after 25% of the filler trials. On average, participants correctly answered these questions 98.2 % of the time, indicating that they were indeed paying attention. Note again that probe questions were not used on critical trials in order to ensure that participants would not develop processing strategies for these stimuli.

Electrophysiological Measures: A commercially available nylon EEG cap containing silver/silver chloride electrodes (Quik-Cap) was used for EEG recording. The EEG was recorded from five midline electrode sites and 22 lateral sites. A cephalic (forehead) location was used as ground. All sites were referenced to the left ear during acquisition and re-referenced off-line to a linked ear reference. EOG was recorded from electrodes placed at the outer canthi of both eyes (horizontal EOG) and above and below the left eye (vertical EOG). EOG artifacts were corrected off-line for all subjects using a rejection criterion of ± 100 µV, in accordance with the procedure outlined in the Neuroscan 4.3 Edit (2004) manual. EEG was sampled continuously with critical EEG epochs time-locked to the onset of each target word of S2: the head Noun, the auxiliary verb, and the word after the verb (i.e., Verb + 1 position; this was never the final position in the sentence). EEG data were amplified using Neuroscan Synamps in a DC-100 Hz bandwidth using a 500 Hz digitization rate. Single trial epochs were created using a -100 to 1100 ms window around the eliciting stimulus and processed off-line using Neuroscan Edit 4.3 software For each participant, ERP averages were computed for each category of critical words in all target continuation sentences. The mean voltage amplitude of the -100 to 0 ms period of each averaged waveform was calculated and served as the 0 μV baseline for post-stimulus activity. The mean amplitude of each waveform was computed in 200 ms intervals from 300 to 1100 ms post-stimulus, yielding 4 mean amplitudes.   These effects were examined across five midline electrode sites (i.e., Fz, FCz, Cz, CPz, Pz) and medial-lateral electrode sites as defined in the Results section below.

3. Results

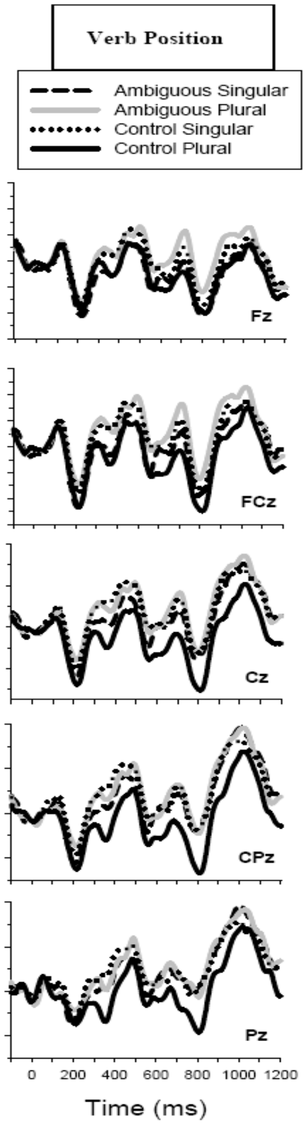
Table 1: F-values for ANOVA at the Verb Position

Analysis	*Effect (df)*	*F Value*	*Mean Square Error*
Midline	E (4, 96)	6.773***	213.37
	T (3, 72)	13.411***	672.28
	E x T (12, 288)	15.049***	50.02
	C x N (1, 24)	7.449*	300.01

C= Context; N= Number; T= Time; E=Electrode; H= Hemisphere.

**p*< .05; ***p*< .01; ****p*< .001

Midline sites: Verb position



For reasons of space, only midline sites at the Verb position will be reported here. For a full account, please see Dwivedi et al, 2008. Late effects were found at the Noun position at about 800 ms; these effects are the beginnings of the significant finding at the Verb position as reported here. Note that no significant effects were found at the V+1 position. Figure 1 shows the grand average waveforms at the Verb position for all 4 conditions at both midline and medial-lateral sites. Visual inspection reveals a long-lasting negativity of AP, AS and CS at midline sites, evident at central to posterior electrodes. This long-lasting effect is also apparent at medial-lateral sites in the right hemisphere, where the sustained negativity is apparent from frontal to posterior sites. Table 1 summarizes the statistical findings.

Although there were no main effects of Context or Number, a Context x Number interaction was revealed (*F* (1, 24) = 7.45, *MSE* = 40.27, *p* = .012). This interaction reflected the long-lasting negativity of the AP, AS and CS conditions as compared to CP.[2] Using Bonferroni correction, pair-wise comparisons revealed that AP was significantly more negative-going than CP (*p*=.003) and similarly, CS was significantly more negative than CP (*p*=.013). Mean voltages for conditions AS and AP did not differ significantly (*p*=.35), nor did AS vs. CS (*p*=.48).

4. Discussion

Our findings generally supported predictions regarding an Nref-like waveform. We did not find any evidence of

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[2] Of course, all EEG activity is reported as either negative-going as compared to a condition or positive going. In the present study, the difference from baseline was a variable used in determining this (as well as theoretical elegance). Note that the mean voltage of AP was -1.09 µvolts, whereas AS was -0.58 µvolts. Similarly, the mean voltage for condition CS was -0.89 µvolts, vs. CP which was 0.14 µvolts.

P600-like effects or N400 effects for the ambiguous conditions, although our filler items, specifically designed to elicit these classic effects, did elicit the expected waveforms (see Dwivedi et al., 2008). Instead, we found that the Ambiguous Plural condition and the Ambiguous Singular condition patterned together, exhibiting sustained negativity. The fact that the Control Singular condition also patterned with the Ambiguous conditions will be discussed below. Thus, the empirical finding was clearly that Ambiguous Plural, Ambiguous Singular, and Control Singular conditions all exhibited a slow negative shift, along midline and right medial-lateral sites, in comparison to the Control Plural condition, starting at about 800 ms after the Noun "tree(s)" was presented and enduring over the time period spanning the next word. Specifically, this effect lasted throughout the presentation of the Verb "was/were" (again, along midline and right medial-lateral sites), and then no significant effects emerged after the Verb (e.g., at "in"). We discuss the significance of these effects below.

Recent work by van Berkum and colleagues has revealed a specific ERP component that is sensitive to the referential ambiguity of NPs, called the Nref. This component is a slow, negative-going waveform, usually with frontal distribution. It appears in continuation sentences when the context has not established a unique referent for a definite NP. For example, Nieuwland, Otten & van Berkum (2007) examined discourses which contained 2 mentions of a particular NP in a context (e.g., in a story, there are two different "nephews", one was *the nephew who was into politics*, whereas the other was *the nephew who was into history*). Continuation sentences that followed such contexts which contained "the nephew" would elicit Nref components. In contrast, this component was not found when the same continuation sentence followed a context where one of the nephews, e.g. *the nephew who was into politics*, left the scene of the discourse, so that only *the nephew who was into history* remained in the story. van Berkum and colleagues explained that this meant that deep processing of the discourse model was indeed occurring, such that the Nref was not simply sensitive to double mention of a potential antecedent but instead represented real sensitivity to referential ambiguity. As such, they indicate that this component can be used to selectively track referential processing in context.

We submit that a likely explanation of our findings is that we have also found an Nref component. That is, if we assume, unlike the findings of Kurtzman and MacDonald (1993) and our own off-line study, that in fact, there is no immediate preference for an interpretation of "*Every kid climbed a tree*" then the result would be a truly ambiguous context. Therefore, the reference associated with either the plural or singular continuation (*The tree(s)*…) would be complicated by the fact that no assignment regarding scope had been made in the previous context sentence. In other words, the context sentence is actually left uninterpreted. As a result, the context sentence does not yield an unambiguous antecedent. When the definite (anaphoric) NP appears in the continuation sentence, the brain/parser must go back and assign a meaning to the ambiguous context sentences so that an antecedent NP can be inferred. This then would allow for the current NP to be integrated into the context. The negative-going waveform is elicited because there is a cost to integrating an NP into a discourse that is ambiguous (either it is the case that two candidate scope possibilities must be held in working memory, or none is held but once the NP is integrated, the work of going back and assigning a meaning must be done, where either of these options requires increased use of working memory resources, resulting in the slow negative shift).

In sum, we believe the reason why the Nref was found for conditions AP and AS is that scope ambiguous sentences, in the absence of previous context, are truly ambiguous—the brain/parser does not assign an immediate interpretation. In contrast, the Control Plural condition, *Every kid climbed a different tree*, is clearly unambiguous. As such, AP and AS are negative-going compared to CP. At this point, we must address why the supposed Control Singular condition, as in *Every kid climbed the same tree* patterned with AP and AS. It is unclear what would be ambiguous in such a sentence. First, our off-line pretest gives us a clue that this "control" condition is unlike the control plural condition. The latter condition produced very strong results for a plural interpretation, 95% of the time. However, the control singular condition, while clearly biased for a singular interpretation at 85%, differed significantly from the Control Plural condition ($p < .001$). Thus, even when participants are under no time pressure to interpret such sentences, they are not doing so in a uniform manner across the control conditions. The question, of course, is from where does the increased ambiguity for control singular derive?

One interpretation can be adduced from linguistic theory. To preview our claim, we will show that the adjective "same", in *Every kid climbed the same tree* has available to it both a sentence-internal and sentence-external reading (which actually results in scope ambiguity, to be shown below) whereas "different" *Every kid climbed a different tree* only has the sentence-internal reading, and as a result is unambiguous. Carlson (1987) discussed the meaning of "same" and "different" and pointed out that these comparative adjectives usually refer to some previously mentioned element in the discourse, called the sentence-external or "deictic" reading, as below:

(1) a. The man went to the same play tonight.
b. Smith went to a different place on his vacation this year.
(Carlson, 1987, p. 531)

For example, the meaning of (1a) is that the man went to the same play tonight as compared to the one we were talking about yesterday. A similar interpretation ensues for (1b). On the other hand, Carlson noted that there are some instances where *same* and *different* do not involve a covert comparison with something previously mentioned in context. Rather, he notes that instead of a sentence-external comparison, sentence-internal comparisons are possible, as the examples below show:

(2) a. Bob and Alice attend different classes (e.g. Bob attends Biology 101 and Alice attends Philosophy 799).
b. The same salesman sold me these two magazine subscriptions (e.g. Salesman Jones sold me this subscription to Consumer Reports, and Jones, too, sold me this subscription to Cosmopolitan).
(Carlson, 1987, p. 532)

In the sentences above, “same” and “different” are now using, as their reference, elements that are found in the sentence-internal context. That is, in addition to a possible sentence-external reading for (2a), where Bob and Alice attend different classes as compared to the ones that you and I like, now a comparison is also possible where they take different classes *as compared to each other*. For (2b), it could the same salesman who came by my house last week who sold me these two subscriptions, or it could be the reading as made clear in (2b), where one salesman sold one person two subscriptions.

Let us assume that in the absence of previous context, the sentence-internal reading is the relevant reading, for our present experiment. If this were the case, then the explanation of the initially surprising findings would be as follows: for sentences such as *Every kid climbed a different tree*, this is interpreted as every child climbing a different tree as compared to every other child, and this would result in a reading where there are many trees climbed by many children. Thus, this is still unambiguous, and the plural interpretation of “tree” is computed.

For sentences such as *Every kid climbed the same tree*, this again, in the absence of context, would be interpreted on its sentence-internal reading, such that every child climbed the same tree as every other child. However, we submit that the presence of the definite article “the” in “the same” vs. “a” in “a different” strongly persuades the brain/parser that a sentence-external comparison might still be worthy of consideration, that is, in addition to the sentence-internal reading.

That is, perceivers are generally ready to easily accommodate information from NPs containing “the” in them, despite the fact that “the N” generally refers to old information, or previously mentioned information (Haviland and Clark, 1974; Heim, 1982; Murphy 1984). As such, despite the overt unavailability of an antecedent, the brain/parser is still willing to entertain the sentence-external meaning associated with “the same”. This is where the ambiguity arises.

Furthermore, this very ambiguity actually results in a scope ambiguity, as defined by linguistic theory (Carlson, 1987). Specifically, the sentence-internal reading is consistent with the surface scope reading, where “every N” is interpreted first, and “the same” is interpreted with respect to “every” (see Barker, 2007). In contrast, the sentence-external reading would require that “the same” take scope over “every”. In other words, this would be the inverse scope reading. Thus, it seems that for this condition, too, the brain/parser waits to assign scope, since both meanings are available to it, and it does not have enough information on which to base a decision. The Nref component is elicited because even though the number associated with “tree” is unambiguously singular on either reading (which was the whole point of including the control context), as it turns out, scope was not assigned. As such, just like with the ambiguous contexts, the control singular context is left uninterpreted. This situation, however, does not arise for “a different N”. Only the sentence-internal reading is regarded, which is the surface scope interpretation. A sentence-external interpretation is discounted because there is no definite article “the” to push the brain/parser in another direction.

In conclusion, we explored simple active sentences that exhibited scope ambiguity using the universal quantifier “every” in subject position, and the existential quantifier “a” in direct object position. We found that such sentences are not disambiguated immediately; instead, the brain/parser waits to assign meaning and this is reflected empirically by a slow-negative shift, labeled recently as the Nref (van Berkum et al., 1999a, 2003).

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