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Processing Bare Quantifiers in Discourse

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Abstract

During reading or listening, language comprehenders construct a mental representation of the objects and events mentioned. This model is augmented and modified incrementally as the discourse unfolds. In this paper we focus on the interpretation of bare quantifiers, that is, expressions such as 'two', to investigate the processes underlying the construction and modification of the discourse model. Bare quantifiers are temporarily ambiguous when sentences are processed incrementally. For instance, in '*Three ships were in the port. Two*…', 'two' can either refer to a subset of the set just mentioned (e.g.,'two of the three ships'), a different set of the entities mentioned (e.g., 'two other ships'), or a set of different entities (e.g., 'two people'). Data from previous studies, and a current completion study, suggest that the subset interpretation is preferred over the establishment of a different set. The current study aimed to investigate ERP correlates of quantifier interpretation and their timing. Quantifiers that unambiguously signaled the establishment of a new referent elicited a late positive component (900-1500 ms), which we interpret as a Late Positive Complex, related to the difficulty involved in context updating. An additional 500-700ms positivity was elicited only in a subset of readers, suggesting that there are individual differences in quantifier interpretation and the timing thereof.

Keywords

ERP; quantifiers; discourse; P600; late positive complex

Introduction

While processing discourse, listeners or readers construct a mental representation of the participants, objects and events mentioned and of the relationship between them (e.g., Heim, 1982; Johnson-Laird, 1983; Kamp, 1981; Kintsch and Van Dijk, 1978). This representation is continuously developed and revised as the discourse unfolds, and incoming phrases are interpreted in the context of this discourse model. For instance, an incoming noun phrase can either refer to a participant, object or event that has been previously mentioned, or can introduce a new referent to the discourse representation (Haviland and Clark, 1974; Prince, 1992). To illustrate, after hearing or reading the sentence, 'A boy and a girl were walking along', the discourse model will contain an entity representing a boy and an entity representing a girl. If the next sentence starts with the noun phrase, 'The boy…', this noun phrase is taken to refer to the boy mentioned earlier, which is an established entity in the

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discourse model. If, on the other hand, the next sentence contains ‘the police officer’, there is no established discourse entity this noun phrase can refer to. In this case, a new discourse referent must be set up in the discourse model. Behavioral research has shown that discourse-new entities are harder to process than information that has been given in the discourse (Haviland and Clark, 1974; McKoon and Ratcliff, 1992). However, the nature and time course of the mechanisms that underlie noun phrase interpretation and the construction of new discourse referents are still unclear. In the present study we focused on the interpretation of quantifiers, to shed more light on these issues.

Quantifiers are expressions such as ‘all’, ‘eight’, or ‘most’. These expressions can only be interpreted if it is clear what to take ‘all’, ‘eight’ or ‘most’ of (Diesing, 1990). This information can be overtly expressed by a following noun and modifiers, as in ‘four children in the room are sick.’ In this example, ‘four’ quantifies over ‘children in the room’. Alternatively, the information can be inferred from the linguistic or wider discourse. For instance, when somebody utters ‘Four are sick’ while looking at mice in a cage, one is likely to take ‘four’ as meaning ‘four of the mice in the cage’. Whether or not the quantifier is followed by a noun, the interpretation is often at least temporarily ambiguous during incremental sentence processing. Consider for instance the quantifier ‘four’ in the fragment in (1).

(1) Six ships appeared on the horizon. Four.…

One possible interpretation of ‘four’ at this point is ‘four of the six ships that appeared on the horizon’. In this case, ‘four’ refers to a subset of the previously mentioned set of six ships. This is what we will call the *subset reading* in the remainder of this paper. In this case, the number word refers to a subset of an entity (or, rather, of a set of entities) that has been mentioned in the preceding sentence, and which is an established referent in the discourse model. Alternatively, ‘four’ can introduce a new set of ships, as in: ‘Four had sunk’ as a continuation of (1), or a new set of different entities, as in: ‘Four people saw them’. In both cases, the number word does not refer to a previously mentioned discourse referent, but introduces a new referent.

Ambiguities such as these may provide insight into the nature and timing of processes involved in discourse comprehension. Analogous to syntactic ambiguities, one can investigate which reading is preferred, and at what point during processing, a particular reading is assigned. Previous behavioral research using off-line completions and forced-choice questionnaires has shown a preference for a subset reading in items such as (1). This has been investigated for English (Frazier, Clifton, Rayner, et al., 2005), Dutch (Wijnen and Kaan, 2006), German and Korean (Frazier, et al., 2005). This preference can be explained either through a general preference to continue the discourse topic (‘Forward directionality’, Hendriks and De Hoop, 2001; Van Kuppevelt, 1996), or by means of the syntactic principle of Minimal Lowering operating at the level of Logical Form (Frazier, et al., 2005). The goal of the present study is to investigate the timing and nature of quantifier processing: in particular, what happens when the quantified expression does not refer to a subset of a previously mentioned set , but instead triggers the establishment of a new referent in the discourse model.

With respect to *when* during processing the quantifier is interpreted, the language processor could either make decisions immediately, analogous to some views of syntactic processing (Friederici, 2002; Mitchell, 1994), or could delay interpreting the quantifier (Frazier, 1999; Frazier and Rayner, 1990; Villalta, 2003). Data from on-line behavioral and eye tracking studies suggest that quantifiers are interpreted at least before the end of the sentence, but are inconclusive concerning the exact time course (Frazier, et al., 2005; Wijnen and Kaan, 2006). These studies used mini-discourses such as the one in (2), in which the number in the second sentence is larger than the number in the first sentence:

(2) Three ships appeared on the horizon. Four….

In this case, the quantifier 'four' cannot refer to a subset of the previously mentioned set of ships, but instead triggers the set-up of a new discourse referent, either a new set of ships, or a new set of other entities. If a subset reading is preferred during on-line processing, readers should experience difficulty for (2) in which a subset interpretation is excluded, relative to (1), which is compatible with subset reading. An on-line stop-making-sense study in Dutch (Wijnen and Kaan, 2006) showed an increase in processing difficulty for items such as (2) versus (1) at the critical quantifier, 'Four' in (2). An eye tracking study in English (Frazier, et al., 2005) showed an increase in first pass and total reading times right after the critical quantifier for items comparable to (2) versus (1). Both studies suggest that people experience on-line difficulty when a subset interpretation is precluded and a new discourse referent needs to be established in the discourse representation. These two studies, however, do not give a detailed insight into the time course of processing: Reaction times in a stop-making-sense study are rather slow (average of 923 ms at the critical position in the Wijnen and Kaan study), and are the result of multiple processes. Furthermore, in the Frazier et al. eye tracking study, the critical number word was not fixated often enough to draw firm conclusions concerning processing at this early position. In addition, behavioral and eye-tracking studies do not yield much information concerning the (semantic or syntactic) nature of the processes involved. For these reasons we investigated processes involved in quantifier interpretation using Event Related Potentials (ERPs).

ERPs have a high temporal resolution, and have been found to be sensitive to various linguistic manipulations. Words that are hard to integrate from a semantic-conceptual point of view generally evoke an N400 component (Kutas and Hillyard, 1980), whereas words that are hard to integrate from a syntactic point of view generally evoke a P600 component (Hagoort, Brown and Groothusen, 1993; Kaan, Harris, Gibson and Holcomb, 2000; Kaan and Swaab, 2003; Osterhout and Holcomb, 1992) and/or Left Anterior Negativity (Coulson, King and Kutas, 1998; Hahne and Friederici, 1999). Only a few studies have investigated ERPs to words that are difficult to interpret or integrate given the discourse model, and these studies have yielded mixed results.

First, a 300-600 ms negativity with a left fronto-central maximum has been found for noun phrases that ambiguously refer to either of two antecedents in the discourse, and hence are harder (or impossible) to integrate into the discourse model, compared to noun phrases unambiguously referred to one particular antecedent (Van Berkum, Brown and Hagoort, 1999). In addition, Anderson and Holcomb (2005) report a Left Anterior Negativity at the noun for definite noun phrases (e.g. 'the cab') that referred to an earlier mentioned entity, compared with indefinite noun phrases that introduced a new entity ('a cab')(Anderson and Holcomb, 2005). Anderson and Holcomb relate this to the difficulty retrieving the antecedent from working memory when the referent has been mentioned previously.

A second component reported in studies looking at noun phrase reference is an N400. This component has been found for the second mention of 'John' in cases such as 'John went to the store because John…,' in which 'John' is not likely to refer to the previously mentioned 'John'. These sentences are compared with cases such as 'Mary and John went to the store because John…,' in which the second John can licitly refer to the same John as mentioned before (Swaab, Camblin and Gordon, 2004). Although it is not clear whether readers established a new discourse referent for the second proper name in these contexts, these results suggests that readers experienced semantic integration difficulty.

An N400 or N400-like component has also been reported for pronouns and repeated proper names that are relatively hard to integrate into the discourse model, either because they refer to more distal as opposed to recently mentioned antecedents (Streb, Henninghausen and Rösler, 2004), or because they refer to antecedents in syntactically non-parallel (harder) positions as opposed to parallel syntactic positions (easier) (Streb, Rösler and Henninghausen, 1999).

The third ERP component reported for words that are difficult to integrate into the discourse context is a late positivity. A posterior positivity in the 550-800ms time range (P600), preceded by a LAN, has been reported for proper names that introduce new discourse referents as compared to pronouns and logophors, which do refer to given referents (Burkhardt, 2005). Similarly, definite noun phrases that introduce new referents have been shown to elicit a P600 compared with noun phrases that have been mentioned before in the discourse, or whose referents could easily be inferred (Burkhardt, 2006). Burkhardt (2005; 2006) interprets the P600 as reflecting additional integration and storage costs elicited by the introduction of a new discourse referent.

Although its connection with the P600 remains unclear, a late positive complex (LPC), starting 400-500ms after the onset of the critical word, has been associated with the ease of retrieval of discourse information and updating of the discourse context (Van Petten, Kutas, Kluender, et al., 1991). Van Petten et al. (1991) found a reduced LPC for open class words that were often repeated in a natural discourse context. These words may be easier to relate to a previously mentioned entity and integrate into the discourse than words that are first mentioned or are not repeated very often. First-mentioned words and words with only a few repetitions either do not have an antecedent in the discourse model, or have an antecedent that is not highly activated. The information association with these words is therefore more difficult to activate and the discourse context harder to update, leading to a larger LPC.

The above studies vary a great deal in their goals, the materials used and comparisons made, which may explain the variety of results. The present ERP study was aimed at investigating the nature and time course of noun phrase interpretation in context using minimally different conditions. In particular, we compared cases in which a quantifier (a number word in this case) introduced a new entity in the discourse, versus cases in which the quantifier could refer to a subset of a previously introduced entity. The critical comparison was therefore that between the second number word in sentences such as ones illustrated in Table 1.

The critical number word was always the first word of the second sentence (underlined in Table 1 for illustrative purposes). The critical second number was either smaller than the first number word (henceforth the Subset condition); or larger, hence introducing a new referent (the New condition). By using number words in the critical word position, potential lexical confounds in the ERPs were minimized. No subsequent noun was provided, thus forcing the new referent to be a set of the same kind of entities that were mentioned in the first sentence, e.g. ‘four other flowers’ in the New condition in Table 1. Note that in order to establish this new referent, the semantic features of the previously mentioned set (‘flowers’) need to be (re)activated. The ‘new’ discourse referent is therefore not an entirely new semantic entity, but is ‘new’ in the sense that the referent is completely separate from the discourse referent previously established.

We first conducted an off-line completion study, using sentences such as the ones illustrated in Table 1, up to and including the critical number word in the second sentence. Based on the studies reviewed above, we expected off-line completions to favor a subset interpretation when the number in the first sentence was greater than that in the second (‘Subset’-

compatible condition), and to have the quantifier refer to a new or different reference set when the number in the first sentence was smaller than that in the second (‘New’-condition).

In the ERP study we expected the following components at the critical number word: First, since the New condition requires both activation of the semantic features of the previously mentioned entity, and the establishment of a new discourse referent, we expected the New condition to engage more working memory processes than the Subset condition. We therefore expected a LAN for the New versus Subset condition. Second, since previous studies found an increase in the N400 component when the antecedent was harder to retrieve, we did not exclude the possibility of an increased N400 component. However, since the semantic features of the antecedent needed to be accessed in both Subset and New conditions, we expected this effect to be rather minimal. Finally, the New condition involves more effort in updating the discourse context, since it involves the establishment of a new discourse referent, which is separate from the discourse referent introduced in the first sentence. We therefore expected an increased P600/LPC for this condition.

Completion study

Results of the completion study are given in Table 2.

When the first number was larger than the second (Subset-compatible condition), participants tended to complete items with the quantifier referring to a subset of the previously mentioned set. When the first number was smaller (New condition), the quantifier often referred to a new referent in the completions [χ^2 =2009.86, df=1, p<.001]. About half of the completions that were classified as ‘new’ completions referred to a set of the same kind of entities as mentioned in the first sentence [923/1751 when the first number was smaller (New condition); 218/460 when the first number was greater (Subset-compatible condition)].

When the first number was greater than the second (Subset-compatible condition), the percentage of ‘subset’-completions was significantly higher than chance [χ^2=382.12, df=1, p<.001]; when the first number was smaller (New condition), the percentage of ‘subset’-completions was significantly lower [χ^2=1733.08, df=1, p<.001]. Thirteen out of the 120 items (10.8%), and five out of 59 participants (8.5%) had numerically slightly more ‘new’ than ‘subset’-completions when the first number was greatest (Subset-compatible condition); on the other hand, all participants and items showed by far more ‘new’ than ‘subset’-completions when the first number was smaller than the second (New condition).

These results show that there was a strong bias in our materials to interpret the critical number word in the New condition as referring to a new entity, and the critical word in the Subset-compatible condition as referring to a subset of a previously introduced set. These findings are in accordance with previous studies (Frazier, et al., 2005; Wijnen and Kaan, 2006).

ERP study

The same set of materials was presented in an ERP study. Participants silently read discourse such as the ones illustrated in Table 1, one or two words at a time, and were occasionally presented with comprehension questions about the immediately preceding sentence pair (see methods section).

Results

Behavioral data

On average, 83% (SD 8%) of all questions were responded to correctly. The mean performance accuracy on the questions following experimental trials was 81% (SD 9%). The accuracy rate for the New conditions was 80% (SD 11%); for the Subset: 82% (SD 9%). There was no significant difference between the conditions [$F(1,29) < 1$, N.S.].

ERPs

Figure 1 depicts ERPs at selected electrodes to the critical number word. No effects were significant before 900 ms. In the 900-1200 ms window, the New condition was more positive than the Subset condition at lateral sites [$F(1,29)=4.52$, $p=.042$]. This continued in the 1200-1500 ms interval for both midline [$F(1,29)=4.26$, $p=.048$] and lateral sites [$F(1,29)=4.92$, $p=.035$] 1. No interaction was found with any location factor.

Individual differences

ERPs at the quantifier—The lack of earlier effects (LAN, N400 or P600 components) at the critical word was rather surprising. Recall that in a self-paced grammaticality judgment study, Wijnen and Kaan (2006) observed differences between the New and the Subset condition immediately at the critical quantifier, with a mean reaction time of 923 ms. In addition, previous ERP studies on discourse processing have typically found effects earlier than 900 ms. To investigate whether potential earlier effects could have been obscured by individual differences (King and Kutas, 1995; Mecklinger, Schriefers, Steinhauer and Friederici, 1995; Osterhout, 1997), we split the participants into two groups of 15 participants each, based on their performance on the comprehension questions (median split). Good comprehenders answered 88 % (SD 7%) of the questions correctly in the New condition and 87% (SD 5%) in the Subset; Poor comprehenders scored 73% (SD 9%) correct in the New condition and 77% (SD 10%) in the Subset. Only the 500-700ms interval showed a weak interaction between condition and group [lateral: $F(1,28)=3.357$, $p=.078$; midline: $F(1,28)=3.228$, $p=.083$]. Whereas Good comprehenders did not show any differences between the conditions in this time window [Fs<1, see Figure 2, upper row], Poor comprehenders showed a positivity for the New versus the Subset condition on lateral sites [lateral: $F(1,14)=4.808$, $p=.046$; midline: $F(1,14)=3.652$, $p=.077$, see Figure 2, lower row]. The 500-700ms positivity was present in 10 out of the 15 Poor comprehenders, and in 4 out of the 15 Good comprehenders. The late positvity was present in 11 out of the 15 Poor comprehenders and 12 out of 15 Good comprehenders. To investigate whether the 500-700ms positivity was different from the late positivity, we compared the effects of Condition in the 500-700ms with that in the 1200-1500ms time windows for the Poor comprehenders only. No interactions with the factor time window were significant [Fs <1], however (see figure 2 for isovoltage maps).

[1]To investigate whether these effects started at the quantifier or at the next word, a separate analysis was conducted on the word following the critical word, relative to a baseline of 100 ms preceding that word. A significant positivity in the 400-1000ms time region, with no significant effects preceding it, would support the view that the 900-1500 ms positivity seen at the critical word was actually triggered by, or at least increased by, the word after the quantifier. However, no significant main effects of condition were found. Results may have been confounded by the differences between participants in the baseline region, as suggested by a Group by Condition interaction 400-700 ms after onset of the word following the critical word [Lateral: $F(1,28)= 4.68$, $p=.039$; Midline: $F(1,28)=4.07$, $p=.053$]: Good comprehenders showed more positive ERPs for the New condition than the Subset; Poor comprehenders showed the reverse pattern. This may be due to the fact that the Poor, but not the Good comprehenders, showed a positivity to the New condition in the baseline region (see main text), confounding the positivity under investigation. It therefore remains unclear whether the late positive effect is triggered by the quantifier or the next word.

ERPs at the final word—To investigate whether the two groups differed in other respects, we also analyzed ERPs to the sentence final word position, see Figure 3.

Overall, ERPs to the New condition were more negative than to the Subset condition. An overall analysis showed a main effect of Condition in the 150-300, 300-500, 500-700 and 700-900ms intervals [*P*s < .01]. For all participants taken together, the negativity for the New condition was largest fronto-centrally in the 300-500ms [Condition by Region: Lateral: F(4,112)=7.82, p=.006; Midline: F(4,112)=4.42, p=.027], and 700-900ms intervals [Lateral: F(4,112)=4.24, p=.042].

The two comprehension groups differed in the following way. First, the Poor comprehenders had overall more negative ERPs in the 300-500ms interval [Midline: F(1,28)=4.71, p=.039], and more positive ERPs in the 700-900 ms interval [Lateral: F(1,28)=5.57, p=.025; Midline F(1,28)=6.20, p=.019] compared with the Good comprehenders. In addition, the negativity for the New versus Subset condition was larger and more broadly distributed in the Poor comprehenders, and was smaller and more frontally distributed in the Good comprehenders. Although these differences were numerically present across the entire epoch, Group only significantly interacted with Condition and Region at midline sites in the 700-900ms interval [Midline: F(4,112)=5.702, p=.014; Lateral: F(4,112)=2.980, p=.089]. Separate analyses on the midline sites for the two groups showed a main effect of Condition in both groups [Poor: F(1,14)=8.014, p=.013; Good: F(1,14)=4.927, p=.043] and a Region by Condition interaction only for the Good comprehenders [F(4,56)=5.282, p=.029]. Good comprehenders showed significant effects of condition only at frontal and frontal-central sites [frontal sites: F(1,14)=6.769, p=.021; fronto-central: F(1,14)=6.653, p=.022; other regions N.S.]. Although the sentence final words were not matched across the conditions, and one, therefore, needs to be careful in interpreting these effects, the differences observed among the two groups support the view that the Poor and Good comprehenders employed different processing strategies.

Discussion

The aim of the present ERP study was, first, to gain more insight into the timing of the processes related to the interpretation of a quantifier cueing the establishment of a new discourse referent, and second, to determine which ERPs component(s) would be sensitive to these processes. On the basis of previous research we expected the New condition to show an increased LAN, N400 and/or P600/LPC component relative to the Subset condition. The New condition only elicited a late positivity versus the Subset condition, starting 900 ms after onset of the critical word. Only participants who scored poorly on the comprehension questions showed a positivity between 500-700ms. At the sentence final position, Poor comprehenders show a larger negativity in the 300-500ms window than the Good comprehenders for both conditions. In addition, the negativity was more centrally distributed for the Poor comprehenders, and more frontally distributed for the Good comprehenders. We will further discuss these components below.

In contrast to expectation, no LAN or N400 differences were found between the two conditions at the critical number word. In both the New and the Subset condition, however, the semantic features of the previously mentioned set needed to be (re)activated. If the LAN reflects working memory effort associated with this reactivation, it is therefore not surprising that no differences were found between the two conditions. Similarly, an N400 effect has been mainly found in studies in which a noun phrase or proper name was repeated (Anderson and Holcomb, 2005; Burkhardt, 2006; Streb, et al., 2004; Streb, et al., 1999; Swaab, et al., 2004) or the antecedent was harder to retrieve (Streb, et al., 2004), regardless of the given/new status of the critical noun phrase referent (Anderson and Holcomb, 2005).

The present study did not use noun repetition, and, as mentioned before, the New and Subset conditions did not differ in the need of accessing the antecedent, or the distance between the quantifier and the antecedent, which may explain the absence of a N400 effect.

The late positivity

In the overall data analysis, the New condition started to differ from the Subset condition only at 900 ms, when the New condition showed a small, broadly distributed positivity, which lasted at least until 1500 ms after onset of the critical word. It cannot be excluded that the present results were affected by the nature of the comprehension questions, which may have induced unnatural reading strategies in which the reader anticipated and actively compared the number words. However, in a number comparison study using the same pairs of number words as in the present experiment (Kaan, 2005), a much earlier positivity (starting at 150 ms) was reported for increasing versus decreasing number sequences. In addition, this positivity was affected by the distance (ratio) between the two numbers. This corresponds to numerous other studies on number comparison reporting effects of distance (e.g. Dehaene, 1996; Moyer and Landauer, 1967). A reanalysis of the current data, in which the materials were split into the same two ratio groups as in the number comparison study, yielded no main effects of distance, or interactions of distance by condition (New versus Subset) [*P*s ranging from .239 to .862]. The present results therefore cannot be completely accounted for by task-induced number comparison strategies.

We would like to propose that the late positive component found for the New versus Subset condition in the current study is an LPC, which has been claimed to be related to the difficulty of activation of previously mentioned discourse entities and context updating (Van Petten, et al., 1991). As mentioned before, the New and Subset conditions do not differ much in the ease of activating the semantic features of the antecedent, but only the New condition involved the establishment of a new discourse referent. We would therefore like to suggest that the LPC primarily reflects this kind of updating of the discourse model, rather than the ease of retrieving semantic features from working memory. Our present finding and the LPC may also be related to a frontal positivity found between 500-900ms at the verb after complex noun phrases such as 'The cake beside that pizzas that <u>were</u>…' versus 'the pizzas that were…' (Kaan and Swaab, 2003), which Kaan and Swaab attributed to an increase in discourse complexity in the former versus the latter component.

Although ERP components only give an upper estimate of the timing involved, and one cannot completely exclude earlier processes, the above data suggests that some aspects of quantifier interpretation are rather slow. This is in contrast to some aspects of syntactic processing where decisions are made rapidly (Friederici, 2002), but coincides with other findings on noun phrase interpretation, which suggest that full interpretation occurs only at the head or clear end of the phrase (Frazier, 1999; Tunstall, 1999). As discussed below, however, the timing of the interpretation may be modulated by individual differences.

Individual differences

A subset of our participants did show an earlier effect. A positivity between 500 and 700ms was found for the Poor comprehenders only. Although this effect was statistically rather weak, a similar effect has been found in situations where a pronoun or noun phrase cannot refer to a previously mentioned entity and, hence, introduces a new discourse referent (Burkhardt, 2005). Although it is unclear whether this early positivity is a component separate from the late positivity, the early positivity is similar in timing to a P600 component. Parallel to the P600 found for words that are syntactically difficult or ungrammatical continuations of a sentence, one can interpret the P600 found here as reflecting either an initial clash with expectation, diagnosis of what is wrong, and/or of revision of the discourse model (Friederici, 1997, 2002). Given this interpretation, the P600 can no longer be viewed as an index of syntactic processing difficulty (e.g. Kaan, et al., 2000), but rather of structurally induced difficulty in general.

The difference between Poor and Good comprehenders can be accounted for mainly as a difference in timing of the commitment to a particular reading. When reading the first sentence, e.g., “Five ships were in the port”, the Poor comprehenders may have assumed a minimal number of ships in the discourse context, in this example, five and no more. Based on such an interpretation, when the quantifier in the second sentence was encountered, e.g., ‘seven…,’ they initially interpreted the quantifier as referring to (a subset of) the previously mentioned set. This misinterpretation led to a referential incongruity, since seven is larger than four; in turn, such an incongruity led to a diagnosis of the problem (Fodor and Inoue, 1994), and the subsequent establishment of a new set of ships. The Good comprehenders, on the other hand, may have had no strong expectations concerning a subset continuation, or a less strong commitment to there being an exact number of ships in the discourse; hence no clash and diagnosis ensued when the number in the second sentence was larger than that in the first (no early positivity). Both Poor and Good comprehenders, eventually needed to adjust the discourse model through the establishment of a new discourse referent, a process we hypothesize is reflected by the LPC. In this respect, discourse interpretation is similar to the processing of syntactic ambiguities, in which High span readers have been shown to be able to retain multiple interpretations in parallel, whereas Low span readers commit themselves to a particular reading early on (but see Friederici, Steinhauer, Mecklinger and Meyer, 1998; MacDonald, Just and Carpenter, 1992; Vos, Gunter, Schriefers and Friederici, 2001).

Additional differences between the two comprehension groups were seen at the final word position. Poor comprehenders showed an increased N400 to both conditions compared to the Good comprehenders. In addition, the Poor comprehenders showed a broadly distributed N400 for the New versus Subset condition, whereas the Good comprehenders showed a more frontal negativity for the New versus Subset condition. N400 effects have been commonly found at the final word of sentences containing mid-sentence syntactic anomalies (Hagoort, et al., 1993; Osterhout and Holcomb, 1992), which have been associated with semantic integration difficulties resulting from earlier parsing interruptions (Hagoort, et al., 1993). The larger N400 effect for the Poor comprehenders corresponds to a finding by Neville and colleagues (Neville, Coffey, Holcomb and Tallal, 1993) that reading disabled and language impaired children showed overall larger N400 components to content words or semantic anomalies than non-impaired controls, suggesting that semantic integration is more effortful in the impaired population. Even though our participants were not language impaired, our Poor comprehenders may have spent more effort integrating words into the semantic context. The interpretation of the frontal negativity seen for the New condition in the Good comprehenders remains speculative. It may be interpreted as a contingent negative variation (CNV), perhaps anticipating a comprehension question, or the use of visualization to construct or re-check the final interpretation assigned to the sentence pair (see the frontal negativity found for concrete as opposed to abstract words (Kounios and Holcomb, 1994), in mental imagery (West and Holcomb, 2000) and picture processing(Holcomb and McPherson, 1994)). Tentative as this may be, the differences found between comprehension groups at the final word suggests that the differences between the two groups not only pertain to the processing of quantifiers, but may be more general.

Conclusion

During reading, readers continually update the mental representation they have of the objects and events mentioned. The present study shows that the interpretation of quantifiers and the establishment of new discourse referents are rather slow processes, but that the timing may be affected by individual differences.

The establishment of a new discourse referent may be reflected by a late positive going component (LPC). If indeed the LPC amplitude reflects the effort involved in establishing a new discourse referent, one expects the LPC to be larger for entities that are completely new to the discourse compared to the present case in which the ‘new’ discourse referent was a different set of the same entities that were mentioned before. This will be investigated in future research.

Materials and Methods

Stimuli

Experimental sentences were of the format illustrated in Table 1. Materials were based on sixty triplets of number words, e.g. *six*, *four*, *twelve*: the first was used as the critical word in the second sentence, the second, smaller number was used in the first sentence in the New condition, the third, larger number in the first sentence of the Subset condition. To avoid long or infrequent words, the critical word was restricted to the numbers ‘three’ through ‘ten,’ ‘twelve’, ‘fifteen’, ‘sixteen’, ‘twenty’, ‘thirty’, ‘forty’, ‘sixty’ and ‘seventy’. Also across the entire set of items, the ratio of the numbers used in the first and second sentence was equal for the Subset and New conditions (mean ratio: 1:1.6). Each of the number triplets was used twice to create two sets of 60 experimental items of the format illustrated in Table 1. The critical word was always followed by a high-frequency verb that was semantically rather empty (e.g. ‘had’, ‘would’, ‘were’, ‘said’). This in turn was followed by a function word (e.g. ‘to’, ‘the’, ‘behind’, ‘very’) in all but 13 items in which a high frequency adjective or participle was used in this position (e.g. ‘small’, ‘large’, ‘given’). The second sentence ended such that the meaning was compatible with the intended Subset or New reading. Note that the second sentences in both conditions were the same at least up to and including the fourth word position. The full set of experimental items can be downloaded from www.clas.ufl.edu/users/ekaan/materials/.

To avoid repetition of the sentence content within participants, two stimulus lists were created according to a Latin Square design such that half of the participants saw the first set of 60 items in the Subset condition, and the second in the New condition; half of the participants saw the item sets in the other conditions. Note that the number words used as the critical words were the same across the Subset and New conditions, both between and within participants. In addition, 120 distracter items were created, yielding a total of 240 trials in the experiment, all consisting of two sentences. The first type of distracter contained an overt noun immediately following the number word in the second sentence. These served to mitigate the participants' expectation of a noun-less quantifier, e.g. ‘Sixteen actors were on stage. Eight people were backstage to help with the props.’ In 15 of these, the number in the first word sentence was larger than in the second, in 15 others, the first number was smallest. The second type of distracter item (30 items) contained a number in the first sentence, but none in the second (example: ‘Three swans were swimming in the lake. The boaters were anxiously trying to avoid them.’). Another 60 distracter items were included that did not contain any numbers (example: ‘The family enjoyed the cruise. Shuffle board is a popular game on board.’) The order of distracters and experimental items was pseudo randomized such that no two experimental items directly followed each other.

Completion study

In order to determine that the materials indeed had a preference for a subset continuation when the critical word allowed this, and that there was a clear difference between the New and Subset conditions in this respect, we conducted a paper-and-pencil completion study. Sixty native speakers of English, all undergraduates or graduates at the University of Florida, were presented with items up to and including the critical number word in the second sentence, and were asked to complete the item fragments with what first came to mind. The 120 experimental items were divided into two main lists of 60 items. Of each of these main lists, two other lists were created by crossing the conditions, such that each list contained 30 different items per condition, and no item occurred in more than one condition on each list. In this way, each item in a particular condition was completed by 14-16 participants. Items were interspersed among 45 distracter items, drawn from the fillers used in the ERP study. The order of the items was pseudo randomized in a different order for each participant. Data from one participant were dropped from analysis because he did not comply with the instructions. Responses were scored as ‘subset-completion’, ‘new-completion’ or ‘missing’ (including ambiguous and illegible completions). Completions were scored as ‘Subset’-completions when the quantified noun phrase clearly referred to a subset of the set mentioned in the preceding sentence (meanings corresponding to ‘Six of those flowers’ in Table 1). ‘New’-completions included completions introducing new set of the same kind of entities as mentioned in the first sentence, e.g. ‘Six (other) flowers…’ for the example in Table 1, as well as completions introducing a set containing new entities of a kind not mentioned before, e.g. ‘Six cats…’ for the example in Table 1. The completion data for non-missing responses were analyzed using χ^2 analysis on a 2 (condition: Subset-compatible; New) by 2 (response: Subset completion; New completion) contingency table.

ERP study

Participants—Participants in the ERP study were 33 healthy native speakers of English, drawn from the undergraduate and graduate student population in the Gainesville, FL area (15 men, 18 women; age 18-30; mean age 21.1). None of them participated in the materials completion study described above. All were right handed as assessed by the Edinburgh handedness inventory (Oldfield, 1971), and none of them had learned a foreign language before puberty. All had normal or corrected to normal vision and had not suffered from neurological disease, trauma, or language-related impairments as indicated by a self-report. Participants gave informed consent before the experiment, and were paid for participation. Data from three participants (3 females) were omitted because of too many artifacts or technical problems.

EEG Procedure

Each trial started with a fixation cross for 700ms. Sentences were presented one or two words at a time. The presentation time for frames with more than six characters was 400 ms, other frames were presented for 300 ms. In the experimental items, the first word of the second sentence (the critical number word) and the two following words were always presented in separate frames for 300 ms. Frames were separated by a 200 ms blank screen. To avoid wrap-up effects of the preceding sentence ending onto the critical word, the two sentences were separated by two frames of hash marks and crosses (‘#x#x#’, ‘x#x#x’), presented at the same rate as the long words in the sentences (400ms, 200 ISI).

To encourage participants to keep paying attention to the sentences, 25% of the trials (40 experimental trials, 20 fillers) were followed by a yes/no comprehension question. These questions either probed the first sentence (‘We picked eight tomatoes. Nine were not completely ripe, so we left them on the plant. Did we pick more than eight tomatoes?’), the second sentence (‘Kim mixed five eggs in eggs in a bowl. Six were about to go bad so she did not use them. Was Kim afraid to use all the eggs?’), or the relation between the first and second quantifiers (‘Five lizards were missing their tails. Four had some scars down their back as well. Did all lizards with missing tails have scars?’) The correct answer (‘yes’ or 'no') was balanced across sentence types. The question was presented in its entirety, 1000 ms after the offset of the last word of a sentence, and remained on the screen until the participants responded. Participants were asked to respond as quickly and accurately as possible by pressing a 'yes' (left) or 'no' (right) button on a game pad. The message 'Press for next' was displayed after the response to the question, or in case there was no question, 1000 ms after the offset of the last word of the sentence. Upon a button press, this message was replaced by the fixation point of the next trial.

The stimuli were divided into 9 runs lasting about 7 minutes each. The order of the runs was different for each participant. Each run started with a distracter item. The first experimental run was preceded by a practice block of five items (two questions) to familiarize the participant with the task. Participants were instructed to read the sentences carefully, and not to blink unless a fixation cross or question was displayed.

EEG recording

EEG was recorded from 38 Ag/AgCl scalp electrodes, using a commercially available elastic cap with active shielding (Easy-Cap) combined with an ANT amplifier (ANT software b.v., Enschede, the Netherlands). Electrode positions used were: Midline: Fz, FCz, Cz, CPz, Pz, POz; lateral left/right: FP1/2, F7/8, F5/6, F3/4, FT7/8, FC5/6, FC3/4, T7/8, C5/6, C3/4, TP7/8, CP5/6, CP3/4, P7/8, P5/6, P3/4 (see Figure 3). Horizontal and vertical EOG was recorded from electrodes placed on the outer canthi, and below and above the right eye, respectively. Additional electrodes were placed on the right and left mastoids. The signal was acquired using the mean of the electrodes as a common reference, but was arithmetically re-referenced off-line to the mean of the left and right mastoids. Electrode impedance was kept below 5 KOhm. The signal was sampled at a rate of 256Hz, and was filtered off-line between 0.3 and 30 Hz. The high-pass filter setting of 0.3 Hz was chosen since we wished to reduce large drift in the signal, and the experiment was not aimed at investigating slow potentials.[2]

ERP Analysis

Epochs comprised 100 ms before to 1500 ms after the onset of the critical word, spanning the first and two following words of the second sentence. For the analysis of the last words, the epoch spanned -100-1000ms. Trials confounded by eye movements, electrode drift and amplifier blocking were rejected (8% rejections on the critical word for the New condition; 10% on Subset; 17% rejection for the last word for both conditions). Average amplitudes for the critical word were computed for the following time windows, based on visual inspection and previous studies: 150-300 ms, 300-500 ms, 500-700 ms, 700-900 ms, 900-1200 ms and 1200-1500 ms after onset of the critical number word, relative to a 100 ms prestimulus baseline. Analyses were conducted on five midline electrodes (Fz, FCz, Cz, CPz, Pz) and on five lateral regions (left/right): Frontal: F3/4, F5/6, F7/8; Fronto-Central: FC3/4, FC5/6, FT7/8; Central: C3/4, C5/6, T7/8; Central-Parietal CP3/4, CP5/6, TP7/8; and Parietal: P3/4,

[2]An analysis with a .01 Hz high pass setting yielded the same pattern of results. No additional effects or slow components were found. With the exception of the 500-700ms positivity for the Poor comprehenders, effects at the critical word were less robust under this more liberal filter, however. This suggests that the 900-1200ms positivity is not an artifact of slow drift, but rather may be obscured by drift when using the more liberal cutoff [Critical word: Positivity for New in the 900-1200 ms interval, main effect of Condition: Lateral: $F(1,29)=1.83$, $p=.187$; Midline: $F(1,29)=2.33$; $p=.138$; Interaction of Condition by Group in the 500-700ms interval: Lateral: $F(1,28)=2.35$, $p=.137$; Midline $F(1,28)=1.86$, $p=.183$; Poor comprehenders show a positivity for the New condition 500-700ms (Lateral: $F(1,14)=5.61$ $p=.033$); Good comprehenders show no difference between the conditions (Lateral: $F(1,14) < 1$; $p=.938$); Word following the critical word: No significant effects, except for a Group by Condition interaction 500-700ms (Lateral $F(1,28)=4.68$ $p=.039$; Midline: $F(1,28)=3.86$; $p= .059$); Last word: increased 500-700ms negativity for Poor comprehenders at midline sites (main effect of Group: $F(1,28)= 3.69$ $p=.065$); increased 700-900 positivity for the Poor comprehenders at midline sites (main effect of Group $F(1,28)= 3.85$ $p=.06$); Negativity for New versus Subset in 300-500, 500-700 and 700-900ms intervals (*P*s <. 035), which does not differ significantly among the groups, except for a Group by Condition by Region interaction in the 700-900ms interval, Lateral: $F(4, 112)=3.35$, $p=.020$; Midline $F(4, 112)=3.36$, $p=.040$].

P5/6, P7/8, using an SPSS multivariate repeated measurements Generalized Linear Model (GLM) with, as within-participant factors, Condition (New/Subset), Region(5) and, where applicable, Hemisphere(2). The univariate statistics are reported, using the p-values corresponding to adjusted degrees of freedom in cases when the number of levels is larger than 2 (Greenhouse and Geisser, 1959). For the comparison between groups, the factor Group (2) was included as a between-participants factor.

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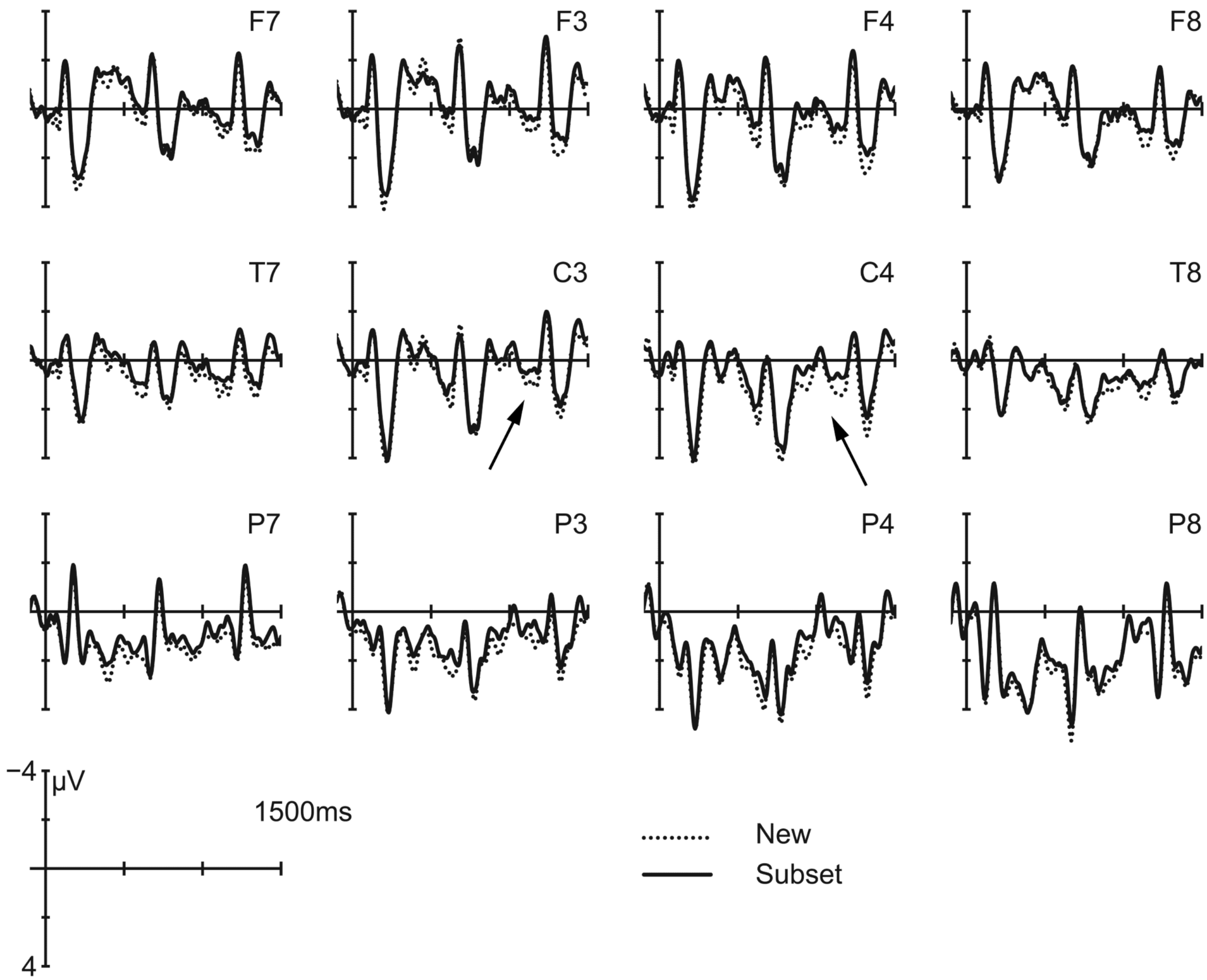

Figure 1.
ERPs to the critical word for selected electrodes. Solid line: Subset condition; Dotted line: New condition. Note the 900-1500 ms positivity for the New condition (arrows).

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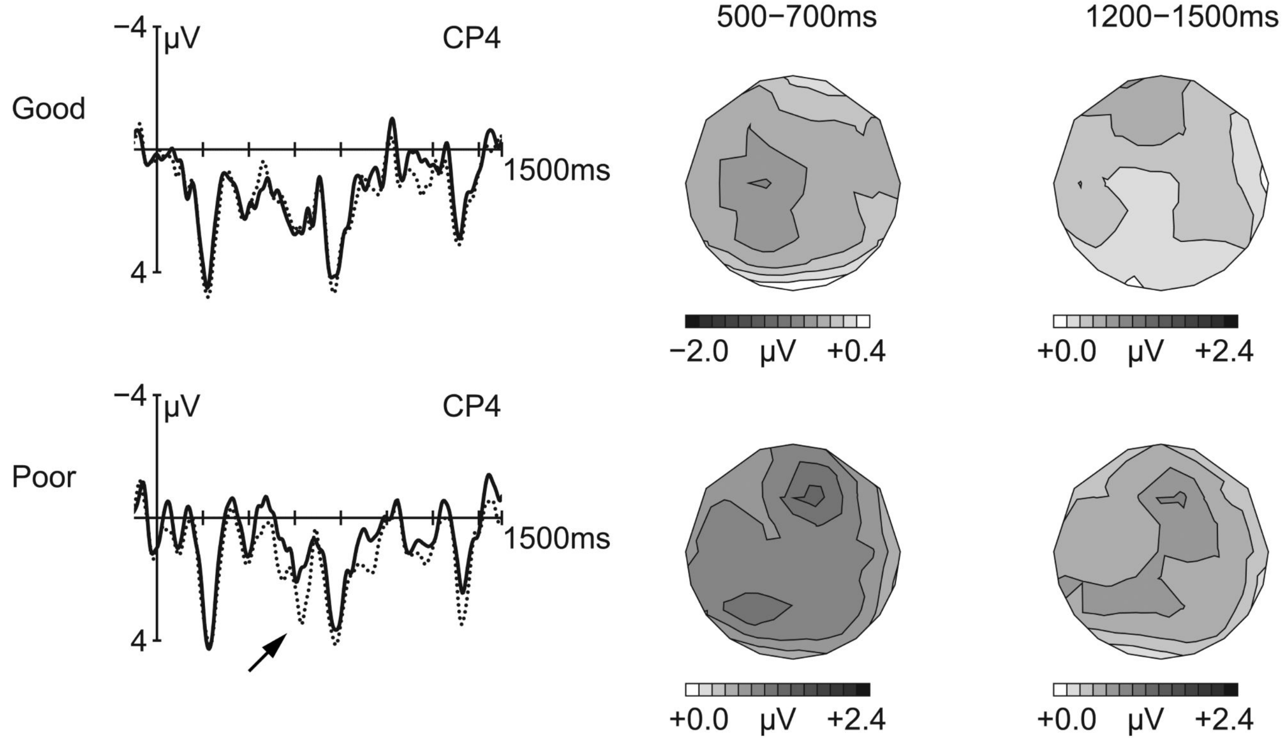

Figure 2.
Left hand side: ERPs to the critical word for the CP4 site. Solid line: Subset condition; Dotted line: New condition. Upper graph: Good comprehenders; Lower graph: Poor comprehenders. Right hand side: isovoltage maps of the difference in ERPs between the New and Subset condition in the 500-700ms and 1200-1500ms interval for the Good (upper row) and Poor comprehenders (lower row). Frontal is up. Note the 500-700 ms positivity for the New condition for the Poor comprehenders (arrow).

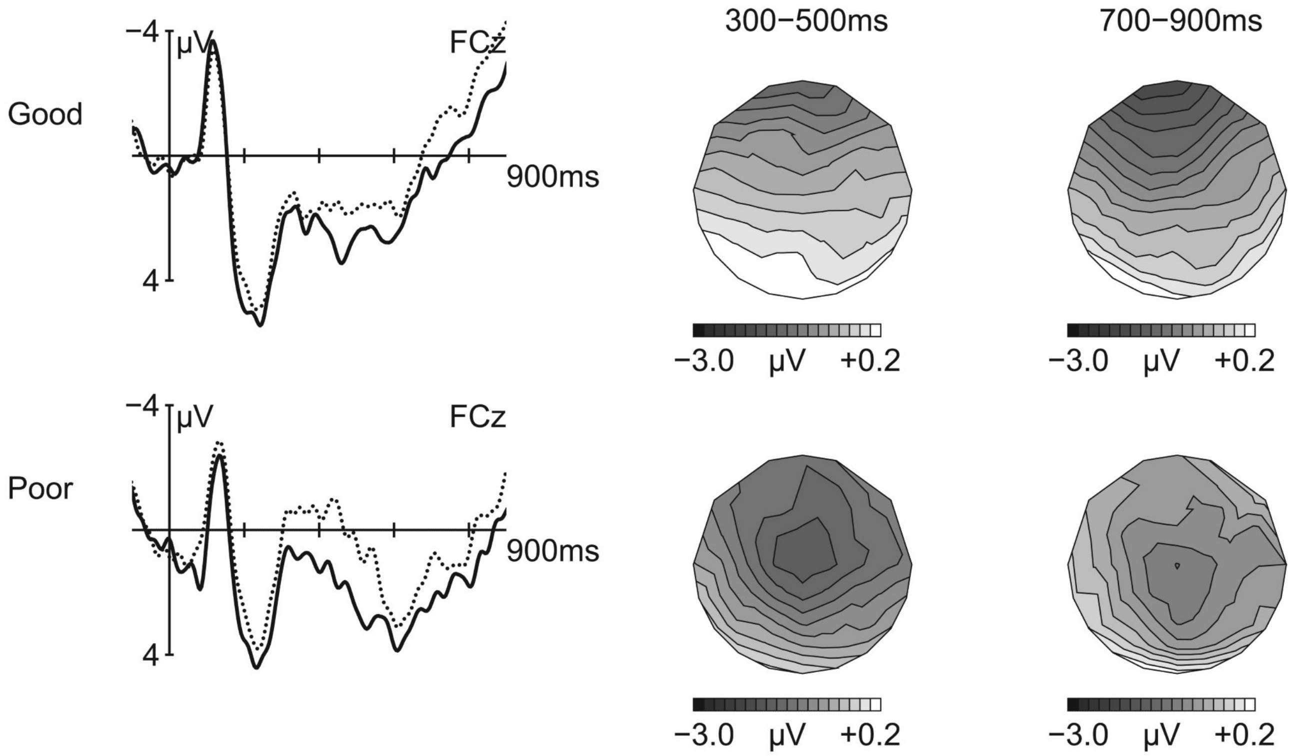

Figure 3.
Left hand side: ERPs to the final word for the CFz site. Solid line: Subset condition; Dotted line: New condition. Upper graph: Good comprehenders; Lower graph: Poor comprehenders. Right hand side: isovoltage maps of the difference in ERPs between the New and Subset condition in the 300-500ms and 700-900ms interval for the Good (upper row) and Poor comprehenders (lower row).

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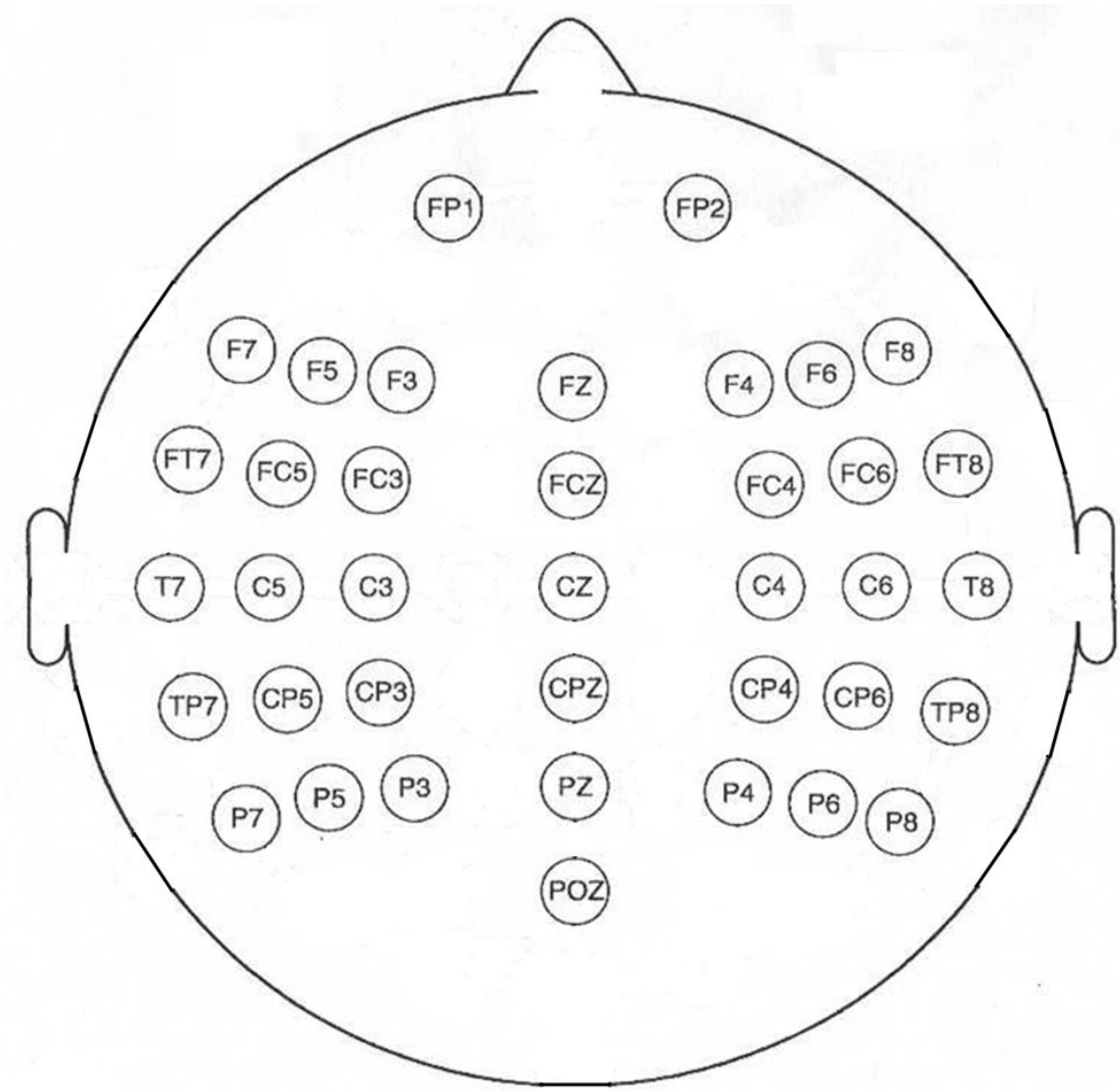

Figure 4.
Overview of the electrodes used.

Table 1

Examples of the two experimental conditions. The critical word is underscored for clarity.

Condition	*Example materials*
Subset	Twelve flowers were put in the vase. Six had a broken stem and had to be cut very short.
New	Four flowers were put in the vase. Six had a broken stem and were trashed.

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Table 2

Absolute number of 'new', 'subset' or ambiguous and missing completions in the New (first number smaller) and Subset compatible (first number larger) conditions. Percentage of completions (out of the total of non-ambiguous/missing responses for the relevant condition) are given in parentheses.

	'New'-completion	**'Subset'-completion**	**Ambiguous/ Missing**	***Total***
New	1751 (99.7%)	6 (0.3%)	13	1770
Subset	460 (26.5%)	1274 (73.5%)	35	1770