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Authors
Hoeks, John C.J.
Stowe, Laurie A.
Wunderink, Charlotte

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Time is of the Essence:
Processing Temporal Connectives During Reading

John C. J. Hoeks (j.c.j.hoeks@let.rug.nl)
BCN NeuroImaging Centre, PO Box 716,
9700 AS Groningen, The Netherlands.

Laurie A. Stowe (l.a.stowe@let.rug.nl)
BCN NeuroImaging Centre, PO Box 716,
9700 AS Groningen, The Netherlands.

Charlotte Wunderink (c.wunderink@let.rug.nl)
BCN NeuroImaging Centre, PO Box 716,
9700 AS Groningen, The Netherlands.

Abstract

An important study by Münte, Schiltz, and Kutas [Nature *395* (1998) 71-73] using ERPs (=Event-Related brain Potentials) suggested that sentences starting with the temporal connective *before* are more taxing for working memory than sentences starting with *after*, as evidenced by a slow negative shift for *before* sentences. According to Münte et al., *before* sentences present events out of the correct chronological order, as in *Before the author submitted the paper* [=second event], *the journal changed its policy* [=first event]. In order to come up with the correct discourse representation of the sentence, the correct chronological order has to be restored, leading to extra memory load. In the present experiments using a self-paced reading paradigm it will be shown that *before* sentences are not more difficult to process than *after* sentences, but that they are even read faster than *after* sentences. In addition, it is shown that *before* sentences in which events are presented in the *correct* chronological order, as in *The journal changed its policy* [=first event], *before the author submitted the paper* [=second event] are read more slowly than corresponding sentences with *after*. Implications for Münte et al.'s theory are discussed and objectives for future research are formulated.

Introduction

Readers do not wait with the interpretation of a sentence until they have received the final word. On the contrary, the process of understanding sentences occurs in a highly incremental fashion, approximately as each word is encountered (e.g., Altmann & Steedman, 1988). A striking illustration of this phenomenon is provided by Münte, Schiltz, and Kutas (1998). In a study using ERPs (=Event-Related brain Potentials), they showed that sentences starting with the temporal connective *before* were processed differently from sentences starting with *after*. Almost immediately after presentation of the temporal connective, the ERP waveforms for the *before* and the *after* sentences started to diverge, with the more negative values for the *before* sentences. Münte et al. argued that this negative shift reflected the additional discourse-level processing that is necessary to deal with sentences that present events out of their correct chronological order. Consider, for instance, sentence 1a, which is an example sentence of the materials used by Münte et al. (1998).

1a. Before the author submitted the paper, the journal changed its policy.

Here, the event of submitting a paper precedes the event of policy change in this specific *sentence*, but in *reality*, the policy change happened first, which can be described as `Before [Event2], [Event1]`. In contrast, sentences starting with *after*, such as 1b, present the events in their correct chronological order, exactly as they purportedly happened in reality: first a submission, then change of policy, so: `After [Event1], [Event2]`.

1b. After the author submitted the paper, the journal changed its policy.

As the size of the negative shift in the ERP waveforms turned out to be highly correlated with the individual working memory spans of the participants (the higher the memory span, the larger the effect), Münte et al. concluded that the problem with *before* sentences is really a working memory problem. In other words, it is claimed that when reading a sentence starting with *before*, readers immediately realize that the events that they are going to read about will have to be re-ordered at some stage to arrive at a coherent and valid semantic representation of the sentence. Thus, the temporal connective *before* may act as a kind of cognitive operator instructing the language processor to hold in memory the event reported on in the first clause, in order to enable the reconstruction of the events in their correct chronological order, presumably after the sentence has been read.

There are, however, a number of problems with this interpretation. First of all, there is no *a priori* reason to interpret a *negative* shift as evidence for processing difficulty or any other form of effortful (memory-related) processing. For instance, a well-known ERP component such as the 'P600' is a *positive* component (occurring about 600 ms post-onset of a critical stimulus), which can be evoked by a number of syntactic problems, such as ungrammatical sentences (Osterhout & Holcomb, 1992), correct sentences with an unpreferred syntactic structure

(Hagoort, Brown, & Groothusen, 1993), syntactically complex sentences (Kaan, Harris, Gibson, & Holcomb, 2000), and even in sentences with a correct syntactic structure that are semantically anomalous (Hoeks, Stowe, & Doedens, 2004). In other words, it cannot be excluded that for some reason or other the *after* sentences are the most difficult, and that this processing difficulty is reflected as a *positive* shift in the ERP signal.

But even if the negativity does indicate processing problems, and the *before* sentences are actually the most difficult, there is another reason why the interpretation of Münte et al might be wrong. For example, if we take a look at the data that Münte et al. provide on the participants with the high and the low working memory score, visual inspection of the waveforms suggests that the ERPs for the *before* sentences actually do not differ between the two working memory groups. Shouldn't these *before* sentences be extra taxing for the group with the smallest working memory capacity, as compared to the high working memory group? What we see instead is a difference between the groups for the *after* sentences, which are more *positive* for the group with the high working memory score. This is quite unexpected, given that the *after* sentences are relatively 'easy' and do not tax memory at all, at least much less than *before* sentences, as Münte et al. claim. In addition, there is only a very slight difference in the low working memory group between the the 'difficult' *before* sentences and 'easy' *after* sentences, which is also rather unexpected. It is not immediately clear how this pattern of results should be interpreted, but it is clear that it does not support Münte et al.'s hypotheses.

In the light of these problematic aspects it seems necessary that two specific issues regarding the processing of sentences with temporal connectives be resolved. First, it is very important to find out whether *before* sentences are more difficult than *after* sentences, or whether it is the other way around. Once this is known, we also know how to interpret the negative shift for *before* sentences reported by Münte et al. Indeed, we might be looking at a *positive* shift, if the *after* sentences turn out to be the most difficult. Secondly, if *before* sentences are more difficult than *after* sentences, we should be able to establish whether this is caused by the chronological order of the events described in the sentence or perhaps by other factors. In the present experiment we will focus on exactly those issues using a self-paced reading paradigm.

The first issue can be tackled rather straightforwardly: by measuring the time people take to read the sentence in either the *before* or the *after* version, we can establish which condition is the most difficult, as it will be read more slowly. The second issue is more complicated, but can be investigated in the following way. Consider sentence 2a, which is an example sentence from the present experiment (with English translation in brackets).

2a. Voordat Piet de sinas dronk, at Stefan de koekjes op.
(Before Piet drank the soft drink, Stefan ate the biscuits)

This sentence presents the events out of chronological order, as did sentence 1a. The 'drinking' event which is mentioned first, actually happened later than the 'eating' event. However, in a sentence such as 2b, the events are presented in their chronological order again.

2b. Stefan at de koekjes op, voordat Piet de sinas dronk.
(Stefan ate the biscuits, before Piet drank the soft drink)

Thus, sentence 2b should not be problematic at all, and be processed faster than a similar sentence with *after* in the second clause (e.g., Stefan ate the biscuits [event2], after Piet drank the soft drink [event1]).

Experiment 1

This experiment is a reading time experiment in which participants read sentences for comprehension and made semantic plausibility judgments after reading each sentence.

Method

Participants Forty native speakers of Dutch were paid for participating in this experiment (28 female; mean age 21 years, age range 18-30). All were currently receiving a university education.

Materials & Design For this experiment, 80 sets of sentences were constructed, each set consisting of eight versions of a given item. Experimental lists were constructed with 10 experimental items per condition, and no list containing more than one version of a given item. All 80 experimental sentences were plausible as determined by two expert raters. An equal number of implausible filler sentences (see sentence 4 below for an example) were added such that each list contain an equal number of plausible and implausible items. The purpose of the semantic plausibility test and the implausible fillers was to encourage deep semantic processing of the experimental sentences.

The order in which experimental and filler items appeared was determined semi-randomly and was the same for each list. Each list was presented to an equal number of participants (i.e., five) and each participant saw one list. Only the first four of the eight conditions belong to the present Experiment 1; the other four conditions were part of a related experiment that will be discussed below as Experiment 2. The experimental sentences for the first experiment appeared in the following forms:

3a. **Before (first clause), Incorrect order (E2 - E1)**
Before Piet drank the soft drink [E2], Stefan ate the biscuits [E1].

3b. **After (first clause), Correct order (E1 - E2)**
After Piet drank the soft drink [E1], Stefan ate the biscuits [E2].

3c. **Before (second clause), Correct order (E1 - E2)**
Stefan ate the biscuits [E1], before Piet drank the soft drink [E2].

3d. **After (second clause), Incorrect order (E2 - E1)**
Stefan ate the biscuits [E2], after Piet drank the soft drink [E1].

The filler sentences had exactly the same form as the experimental sentences (in exactly the same quantities) but were semantically implausible, as sentence 4.

4. Before the murder was committed, the police found the dead body.

A practice session consisting of 30 items preceded the actual experiment.

Procedure Participants were seated behind a computer screen in a sound-proof cabin. Each sentence was preceded by an asterisk indicating the start of a new sentence. Participants were instructed to use the 'b'-key on a keyboard before them to read the sentence clause-by-clause. That is, after the first key-press the asterisk disappeared and the first clause appeared (e.g., "Before Piet drank the soft drink,"); after the second press the first clause disappeared and the second clause appeared (e.g., "Stefan ate the biscuits."); at the next press the second clause disappeared and the question "Goed?" (="Correct?") appeared. Participants had to press the right SHIFT button to indicate that the sentence was semantically plausible, and the left SHIFT button if they felt it was not. Each response was followed by feedback on the correctness of the answer (i.e., "Correct!" / "Wrong!"). Participants were asked to read the sentences carefully and to respond as quickly as possible without compromising accuracy. After the feedback the asterisk reappeared. In all, the experiment took approximately 20 min.

Results

Analysis First, reading time data were screened for outliers. Reading times less than 200 or greater than 4000 ms were excluded. After that, all observations were excluded which deviated more than 2.5 SDs from either the participant or the item mean of each clause in each condition. Two analyses were performed: an $F1$-ANOVA on the condition means for each participant and an $F2$-ANOVA on the condition means for each item. The factors Temporal Connective (*before* vs. *after*), Connective Position (in first clause vs. in second clause), and Clause (first clause vs. second clause) were treated as within-participants and within-items factors. In the participant-based analyses, the factor List (i.e., grouping together participants that were presented with the same list) was also included in the analyses as a between-participant factor, and in the item-analyses the factor Itemgroup (i.e., grouping together items that appeared in the same condition in each list) was entered as a between-items factor. Both factors had 8 levels as there were 8 lists and 8 itemgroups (see design section above). In addition, accuracy percentages were calculated per condition. Mean reading times and accuracy are presented graphically in Figure 1.

Accuracy As can be seen in Figure 1, accuracy was high for each condition (overall accuracy 90 %). No significant interactions or main effects were found (all F-values < 1).

Reading Times The 3-way interaction between Temporal Connective x Connective Position x Clause was significant in the analysis on items ($F2(1,72)=4.12$; $p<.05$) and marginally significant in the participant analysis ($F1(1,32)=3.23$; $p=.08$). Post Hoc analyses showed that there was no significant difference between *before* and *after*

sentences as far as the first clause is concerned (though reading times of first clauses containing *before* were numerically smaller than those of first clauses containing *after*). Much larger differences were found in the second clause. The second clause of sentences with *before* in the first clause was read significantly faster than of sentences with *after* in the first clause ($p<.05$). The opposite pattern, however, was found for the sentences with the temporal connective in the second clause: here, the *before* sentences were read more slowly than the *after* sentences, though this difference was only marginally significant ($p=.09$).
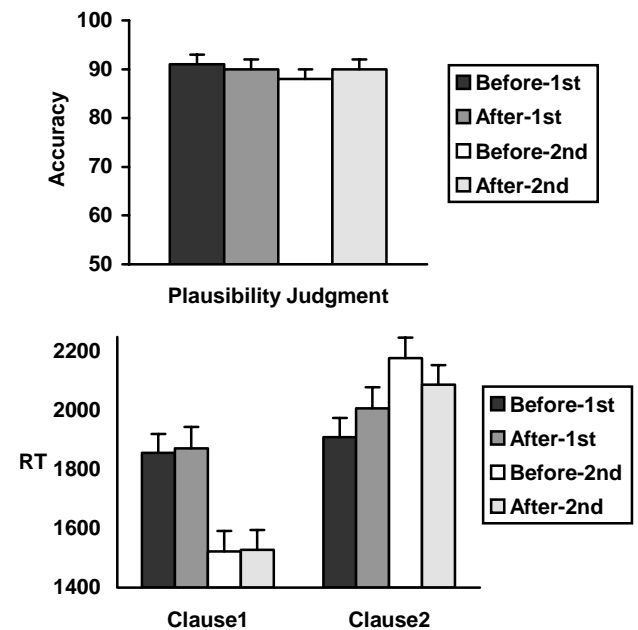

Figure 1. Accuracy (in percentages, upper panel) and Reading times (in ms, lower panel) for Experiment 1. "Before/After-1st"=temporal connective in first clause; "Before/After-2nd"= connective in second clause.

A number of other effects were significant, which should of course be interpreted with caution in the presence of the significant 3-way interaction. For instance, the 2-way interaction of Connective Position and Clause was significant ($F1(1,32)=107.16$; $p<.0001$; $F2(1,72)=87.80$; $p<.0001$), reflecting longer reading times for the clause in which the temporal connective was present (connective in first clause: first clause: 1865 ms, second clause: 1525 ms; connective in second clause: first clause: 1959 ms, second clause: 2138 ms). More interestingly, there was also an interaction between Connective Position and Temporal Connective ($F1(1,32)=5.06$; $p<.05$; $F2(1,72)=4.80$; $p<.05$), indicating that *before* sentences as a whole were read faster when the temporal connective appeared in the first clause (*before*: 1884 ms; *after*: 1940 ms) than when it appeared in the second clause (*before*: 1854 ms; *after*: 1808 ms). No other effects concerning Temporal Connective were significant (all F-values < 1). The factors Clause (Clause 1: 1695 ms; Clause 2: 2048 ms) and Connective Position (connective in first clause: 1912 ms; in second clause: 1831

ms) had significant main effects (F1(1,32)=34.80; p<.0001; F2(1,72)=84.98; p<.0001, and F1(1,32)=10.08; p<.005; F2(1,72)=13.69; p<.0001), respectively).

Discussion

This experiment yielded two important results. First, in the conditions where the temporal connective appeared in the first clause, there was no evidence at all for *before* sentences being more difficult than *after* sentences as expected on the basis of Münte et al.'s arguments (1998). Quite on the contrary, the first clause of *before* sentences was read numerically faster than the first clause of *after* sentences. More importantly, the second clause of *before* sentences was read *significantly faster* than that of *after* sentences, with an average advantage of 97 ms for the *before* sentences. This finding clearly indicates that *before* sentences are in fact easier to process than *after* sentences, contra Münte et al.'s predictions. So perhaps the slow negative shift for the *before* sentences is actually a slow *positive* shift for the more difficult *after* sentences.

The second important result comes from the conditions where the temporal connective was placed in the second clause. Here, we see no difference in reading times in the first clause, which is as one would expect given that there is no difference between the conditions yet, as the temporal connective only appears in the second clause. We do see substantial differences in the second clause, but in a direction opposite to Münte et al.'s predictions. Recall that the *before* sentences with the temporal connective in the second clause present the events in the correct chronological order (see sentence 3c), in contrast to sentences with *after* in the second clause (see sentence 3d). This should have solved the problems of increased memory load and thus have led to a processing advantage for the *before* sentences as compared to the *after* sentences. However, what we find is a 110 ms *dis*advantage for *before* sentences with the events in the 'correct' temporal order. This strongly suggests that presenting events out of chronological order does not lead to processing difficulty. It even seems that presenting events in the correct chronological order leads to an increase in processing difficulty.

Summarizing, this experiment showed, contrary to expectation, 1) that sentences starting with *before* are easier to process than sentences starting with *after*, and 2) that presenting events out of chronological order does not cause processing difficulty.

Experiment 2

Experiment 1 was intended to answer two straightforward questions about the processing of temporal connectives: 1) are *before* sentences more difficult than *after* sentences, and 2) is that the case because before sentences present events out of chronological order? We have seen that neither one was true. Experiment 2 was more exploratory, focussing on the possible interaction between *temporality*, or the chronological ordering of events, with the processing of *referential expressions* which is another important aspect in the construction of a coherent discourse representation (Garnham, 1999). The main issue here is whether temporal and referential processing draw on the same resources, or whether they are processed in parallel by independent mechanisms.

It is assumed that the use of referential elements such as pronouns (e.g., 'he' or 'she') in a sentence may increase the processing load during comprehension. When a pronoun is encountered, a search process needs to be initiated in order to find the intended *referent* for the pronoun (i.e., the person or thing that is referred to by the pronoun). It has been shown that this search process can be more costly than for instance having a proper name (e.g., *Stefan*) where no search process is necessary (Streb, Rösler, & Hennighausen, 1999).

In Experiment 2, the materials from Experiment 1 were used, except that in each sentence a pronoun was inserted, as in sentence 5a.

5a. Stefan at de koekjes op, voordat hij de sinas dronk.
(Stefan ate the biscuits, before he drank the soft drink)

In this sentence, the pronoun *he* appears in the second clause and is used *anaphorically*, that is, it refers back to an entity that is mentioned earlier (in this case *Stefan*). Although there is a pronoun present that might induce a search process, it does not seem likely that in this specific case this search process is in any way difficult. In fact, in a sentence such as 5a there is only one possible referent (i.e., *Stefan*) and the use of a proper name, permitting immediate identification of the referent, would even be sub-optimal (see e.g., Gordon, Grosz, & Gilliom, 1993, regarding a phenomenon called the 'repeated name penalty'). However, if the pronoun were to *precede* its referent, this might be taxing for working memory, or lead to other processing difficulty, because it will not be possible to fully process the clause that contains this pronoun before the referent is known. Consider 5b, for an example of such a sentence.

5b. Voordat hij de sinas dronk, at Stefan de koekjes op.
(Before he drank the soft drink, Stefan ate the biscuits)

In this sentence, the pronoun is used as a *cataphor*, or *backwards anaphor* (Garnham, 1999), and refers to an entity that will be mentioned later. Because the first clause cannot be fully interpreted as it lacks crucial information on whom the pronoun refers to, and because the reader does not know when this referent will be presented, it seems reasonable to assume that these sentences are difficult to process, as compared to sentences such as 5a. If this kind of effortful processing of cataphors is handled by the same mechanism that is responsible for temporal processing one would expect an interaction between these two factors. If, on the other hand, these two kinds of processes proceed in parallel and are carried out by independent systems, then there will be no interaction.

In summary then, Experiment 2 aims to clarify two things:
1) whether cataphoric constructions are more difficult to process than anaphoric ones, and
2) whether this difference in processing load has a (possibly differential) effect on how *before* and *after* sentences are handled. In other words, do temporal and referential processes interact?

Method

Participants, Design, & Procedure Participants, design and procedure are described in the method section of Experiment 1.

Materials Most aspects of the materials are described above in the materials section of Experiment 1, except for the conditions of the current experiment, which were the following:

6a. **Before (first clause), Incorrect order, cataphor**
Before <u>he</u> drank the soft drink [E2], Stefan ate the biscuits [E1].

6b. **After (first clause), Correct order, cataphor**
After <u>he</u> drank the soft drink [E1], Stefan ate the biscuits [E2].

6c. **Before (second clause), Correct order, anaphor**
Stefan ate the biscuits [E1], before <u>he</u> drank the soft drink [E2].

6d. **After (second clause), Incorrect order, anaphor**
Stefan ate the biscuits [E2], after <u>he</u> drank the soft drink [E1].

Note that a full factorial design is not possible, as sentences with a pronoun in the first clause and a connective in the second clause are ungrammatical when the pronoun is intended to refer to the entity mentioned in the second clause (as in: "He$_{(i)}$ drank the soft drink, before Stefan$_{(i)}$ ate the biscuits"). Instead, a reduced design was chosen that would enable us to answer some important questions regarding the interaction of temporal and referential processing.

Results

Analysis After screening for outliers (see Experiment 1), mean RTs and mean accuracy percentages in each condition were calculated for both participants and items. Figure 2 presents the mean reading times and accuracy for Experiment 2.

Accuracy As can be seen in Figure 2, accuracy was high for each condition (overall accuracy 87 %). The main effect of Temporal Connective was marginally significant in the participant-based analysis ($F1$(1,32)=2.80; p=.10), but not in the item-based analysis ($F2$(1,72)=1.74; p=.19), indicating a trend for slightly greater accuracy in the *before* sentences (89%) as compared to the *after* sentences (86%). There was no significant effect of Connective Position (F-values < 1).

Reading Times The 3-way interaction between Temporal Connective x Connective Position x Clause was not significant in the present experiment (both F-values < 1). The interaction of Temporal Connective and Clause was significant in both participant-based and item-based analyses (F1(1,32)=5.89; p<.05; F2(1,72)=8.95; p<.005). This interaction is caused by *before* sentences taking longer than *after* sentences in the first clause (i.e., 1558 vs. 1519 ms, respectively) with a reverse pattern for the second clause (i.e., *before*: 1917 ms vs. *after*: 1999 ms). None of these two separate contrasts were significant, however (p-

values>.20). Perhaps more importantly, there was also a trend towards an interaction between Temporal Connective and Connective Position (F1(1,32)=3.07; p=.09; F2(1,72)=1.67; p=.20), suggestive of shorter times for *before* sentences as a whole when the temporal connective appears in the first clause (i.e., *before*: 1704 ms vs. *after*: 1762 ms), contrasting with the pattern of results when the temporal connective appears in the second clause (i.e., *before*: 1771 ms vs. *after*: 1756 ms).
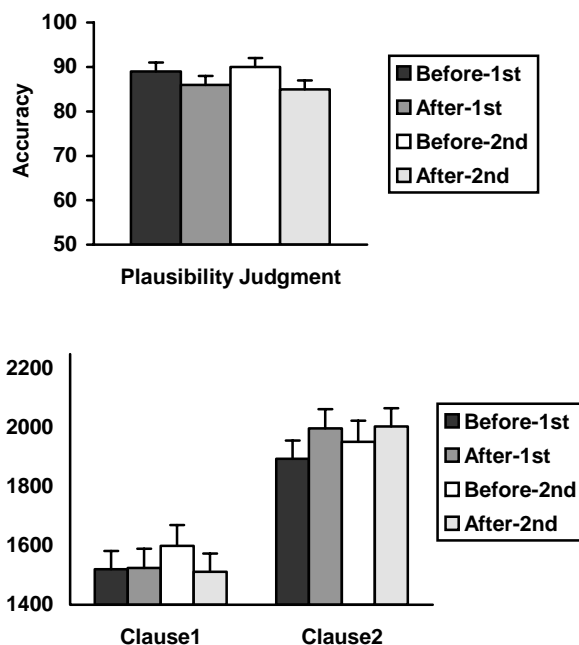

Figure 2. Accuracy (in percentages, upper panel) and Reading times (in ms, lower panel) for Experiment 2. "Before/After-1st"=temporal connective in first clause, pronoun is cataphor; "Before/After-2nd"=temporal connective in second clause, pronoun is anaphor.

As to the main effects, there was a marginally significant main effect of Connective Position (F1(1,32)=1.55; p=.22; F2(1,72)=3.06; p=.09), suggesting that sentences take longer to read when the temporal connective appears in the second clause than when it is present in the first clause (i.e., 1764 ms vs. 1733 ms). Finally, there was a significant main effect of Clause (F1(1,32)=56.37; p<.0001; F2(1,72)=195.57; p<.0001), reflecting the large difference in reading times between first clause (1539 ms) and second clause (1958 ms). There was no main effect of Temporal Connective (*before*: 1737 ms; *after*: 1759 ms; p-values >.30).

Discussion

The aim of this experiment was to establish whether cataphoric constructions were more difficult to process than anaphoric ones, and also whether any difference between them would affect the processing of temporal structure. Some tentative evidence for such an interaction seems to come from the finding that *before* sentences are faster than

after sentences when containing cataphors, but not when containing anaphors. However, this might very well be the result of an unfortunate 'blip' in the data, that is, the fact that reading times for the first clause differ between conditions that had identical first clauses (i.e., of sentences with the connective in the second clause). It is not unlikely either that the marginally significant main effect of Connective Position, another indication of a possible difference between cataphors and anaphors, is caused by just that spurious effect. So what can we say about cataphors and anaphors then?

What we can say about cataphors is that they do not seem to be hard to process. Perhaps the most striking difference between the present two experiments is the large reduction in first clause reading times when proper names / NPs (i.e., in Exp. 1) are replaced by cataphoric pronouns (i.e., in Exp. 2), indicating that inserting cataphoric pronouns makes sentences easier. However, because these clauses differ between experiments in the lexical material they contain, no strong conclusions can be drawn from this outcome. What is equally apparent, however, is that cataphors do not *create* a difference between *before* and *after* sentences: there is no difference at all in the first clause and only a slight difference in the second clause, which is numerically almost identical to the pattern of results in Experiment 1 (for sentences with the temporal connective in the first clause, see also Figure 1). As for anaphors, it seems clear that they do not cause processing difficulty either. On the contrary, they seem to make the processing of *before* sentences easier, if we compare the results of both experiments: In Experiment 1 *before* (with the correct order of events) was read more slowly than *after* (with the incorrect order of events) in the sentences with the connective in the second clause; in Experiment 2 this is (numerically at least) the other way around. In summary then, the outcome of this experiment strongly suggests that cataphors are not difficult to process, that anaphors are even easier, and that chronological order of events is not a factor of importance.

Conclusion & Future Directions

The present experiments have convincingly shown that *before* sentences are actually *easier* to process than *after* sentences. In addition, it has become clear that the chronological order of events does not strongly influence ease of sentence processing. Finally, as there was no strong evidence for an interaction between temporal and referential processing, it is still a bit unclear whether these two kinds of information are processed by the same or by different cognitive mechanisms.

When we try to understand the Münte et al. results in the light of the present findings, we must conclude that the slow potential difference building up while the sentence is read should not necessarily be interpreted as a negativity for the *before* sentences, but rather as a positivity for the *after* sentences. In addition, this slow wave difference does not seem to be related, or at least not directly, to presenting events in or out of their correct chronological order, nor with memory processes *per se* (recall that the low working memory group from Münte et al. did not show a difference between *before* and *after* sentences). This leaves us with a

lot of new questions: why are *after* sentences more difficult to process than *before* sentences? and how should we then conceive of the relationship between working memory capacity and temporal processing, if it does not work as Münte et al. hypothesized? It is possible that connectives (and also pronouns) evoke certain processing strategies that do not tax memory, or only minimally. Hoeks and Stowe (2002), for instance, have speculated that *before* might activate a relatively cost-free 'temporal ordering frame' (maybe only available for individuals with high working memory capacity?) that allows for fast sentence integration, whereas *after* does not. More research focussing on these processing aspects of temporal connectives is definitely needed. But also research using language corpora in order to establish both form and function of different kinds of temporal expressions in text and communication.

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