Verbs in spoken sentence processing

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CHAPTER 6. CLAUSE BOUNDARIES

1. INTRODUCTION

In the previous chapters, the focus was on the main clause and, more specifically, the role of the matrix verb in this clause. Although complex sentences consisting of two clauses were used in all experiments, and in some experiments a probe position occurred after the main clause, the second clause was largely ignored. In Experiments 1 and 2, probes were placed after the conjunction, that linked the second clause to the main clause. At these points, no activation of the meaning of the matrix verb was demonstrated. This suggests that this verb remains active during the main clause, but once a clause boundary is encountered, the activation vanishes. Until now, the implicit assumption has been that the lack of activation would continue during the remainder of the second clause. In the present chapter this assumption will be tested by probing for verb activation at later positions in the second clause. Also, the robustness of the clause boundary effect will be examined in more detail. After a short review of the literature, relevant data from experiments presented in earlier chapters will be summarized, and data from three new experiments will be presented.

2. PROCESSING AROUND THE CLAUSE BOUNDARY

2.1. Introduction

The clause is both syntactically and semantically a relevant unit. Syntactically, it represents the highest unit of analysis in the syntactic tree and thus subsumes all other types of phrasal constituents. Semantically, it is important because the predicate expresses the event described. According to Börjars and Burridge (2001) a clause is ‘the unit formed around a lexical verb, containing all the bits that the verb requires as well as any optional bits the speaker has chosen to include.” (p. 212).

1 A clause always consists of at least a subject and a predicate, the predicate contains the verb and its complements.
2.2. Clauses and clause boundaries

The salience of the clause as a basic unit in language processing has been acknowledged since the ‘60s. For example, a self-paced reading experiment showed that more time is spent at the end and beginning of a clause when sentences are read for recall (Aaronson & Scarborough, 1977). Also, the results of click experiments, where participants have to report where in a spoken sentence they perceive a clicking noise, converge on the finding that clicks are substantially more often reported at clause boundaries (Abrams & Bever, 1969; Bever, Lackner, & Kirk, 1969; Reber & Anderson, 1970; Garrett, Bever, & Fodor, 1966).

The activation level of particular words in a sentence decreases significantly after a clause boundary, as found in explicit recognition or recall tasks (Fallon, Kuchinsky, & Wingfield, 2004; Reilly, 1993; Jarvella, 1971; Caplan, 1972). The general interpretation of these data is that the clause is the basic unit for memory of sentences. At clause boundaries all information present in the recent clause is transferred to a more permanent memory store, and detailed surface information is erased from immediate memory. Thus, not the specific words, but rather the general message (or proposition) of a clause is retained.

Caplan (1972) presented participants with spoken sentences followed by a probe word, and asked them to indicate as quickly as possible whether the probe word was or was not included in the sentence. Participants heard one of two critical sentences in which the last words, including the probe word, were identical. Importantly, the probe word (oil) was part of the last clause in sentence (1), but it was part of the penultimate clause in (2).

(1) Now that artists are working fewer hours, oil prints are rare.
(2) Now that artists are working in oil, prints are rare.

Participants were significantly slower to recognize the probe word when it occurred prior to the clause boundary, as in (2). This effect was replicated with spoken probe words (uni-modal design). On the basis of these results, Caplan (1972) suggested that sentence comprehension involves a process of encoding the sentence meaning on a clause-by-clause basis: if a word is part of the most recent clause encountered, it should be more readily available in working memory than if it was part of an earlier clause (even when the word’s absolute position relative to the end of the sentence is held constant).

In line with these results, Jarvella (1971) found that verbatim recall was most accurate for the most recent clause of the most recent sentence in an experiment using spoken passages consisting of multiple complex sentences. These passages were unexpectedly interrupted and participants were asked to recall as much of the preceding speech as
possible. In a similar experiment, recall predominantly started at a clause boundary and contained one clause or a two-clause sentence (Fallon et al., 2004).

Roberts and Gibson (2002) pointed out that the earlier experiments might have confounded the number of clauses with the length or complexity of the sentences. They tested this alternative hypothesis in an experiment where participants listened to sentences containing two to five clauses and answered questions immediately after each sentence. These questions concerned either the Subject or the main verb of one of the clauses. The sentences varied not only in number of clauses, but were also systematically manipulated to contain more or fewer noun phrases and more or fewer discourse referents. The results did not provide evidence for their alternative hypothesis, but were in line with the earlier experiments: an effect was found for the number of clauses, but not for the two complexity measures used.

Reilly (1993) replicated these memory-related findings in a simulation with a connectionist model (simple recurrent network model). Both accuracy and speed of recall were found to be impeded by the presence of sentence and clause boundaries.

Whereas the data from tasks measuring explicit memory for (words encountered during) clauses all converge on the same findings, results are less straightforward when more implicit tasks, measuring priming effects, are used (Camblin, Federmeier, & Kutas, 2000; Swinney & Hakes, 1976; Swinney et al., 1979).

Swinney et al. (1979) studied the influence of the clause boundary on semantic priming during spoken sentence comprehension in a CMLP paradigm. They compared lexical decisions to visual word probes immediately following a related word in the spoken sentence, and three syllables later. Furthermore, they manipulated whether or not a clause boundary intervened between the prime and the probe. Both Subject- and Object-relative clauses were used. Significant priming effects were found in all four conditions (although the effect was only marginally significant in the condition where the probe was presented after three syllables and an intervening clause boundary). It was thus concluded that semantic priming is unaffected by an intervening clause boundary. At first sight this finding seems to be at odds with the data presented before, that converged on the conclusion that information about specific words presented in previous clauses is no longer available for conscious access. A possible reconciliation, put forward by the authors, is that the lexical decision task taps into unconscious processing. That is, the automatic priming effect does not rely on the active presence of the prime word in working memory. Rather, the processor might have tapped into general semantic information about the lexical material in the previous clause.

More recently, Camblin, Federmeier, and Kutas (2000) compared N400 priming effects for related word pairs that occurred within the same clause (3) or were separated by
a clause boundary (4). Priming is reflected in the EEG wave pattern as a reduction in N400 amplitude to a word (*queens* in this case) when it is preceded by a related word (*kings*).

(3) The book described the kings and the queens but lacked details she needed.
(4) The book described the kings, but the queens were not mentioned at all.

A standard N400 priming effect was found when the words appeared in the same clause. Yet, when a clause boundary intervened, the effect occurred later and had a different distribution. These results are in line with the data from Swinney et al. (1979) in demonstrating that priming effects can cross clause boundaries. However, the results can be taken to suggest that the clause boundary does have an effect, though subtle, on unconscious processes like priming; the ERP pattern differed in timing and distribution from the standard priming effect.

An alternative interpretation might be a difference in wrap-up effects between the two sentences. A number of studies report wrap-up effects appearing at the end of a sentence or clause which are reflected by longer reading times (Rayner & Sereno, 1994; Rayner, Kambe, & Duffy, 2000), priming of filler words processed earlier in a sentence (Balogh et al., 1998), and negativities in ERP research (Felser et al., 2003; Gunter, Jackson, & Mulder, 1995; Hagoort, 2003). Wrap-up effects are generally interpreted to reflect integrative processes. For example, Budiu and Anderson (2004) claim that “... the cognitive system spends some time at the end of the sentence (or clause) to coherently relate the current sentential input to prior (episodic or permanent) knowledge” (p. 10). Both ERP results (Hagoort, 2003) and eye-movement data (Hill & Van Gompel, 2005) suggest that syntactic as well as semantic/lexical processes play a role during wrap-up. Hagoort (2003) reported a sentence-final N400 effect reflecting processing problems earlier in the sentences for semantic violations, syntactic violations, and a combination of both types. Based on reanalysis effects during reading (regression path times), Hill and Van Gompel (2005) concluded that readers engage in both additional syntactic and lexical processing at the end of a sentence.

It is clear that wrap-up processes overlap with the ‘memory shunting processes’ discussed before. However, there seem to be extra factors involved, probably best described as ‘checking mechanisms’, since these wrap-up effects are reported to reflect different types of violations that occurred earlier in the sentence.

2.3. Implications for the present study

In short, the literature suggests that the clause is an important element showing effects both in off-line, conscious measures and during on-line processing. At the end of a clause
(or sentence), the general message of the clause is transferred from a temporary, working memory system into a more permanent part of memory. After this process, information from the previous clause is available again (if necessary), although at a more general level. Also, the clause boundary seems to be a general ‘checkpoint’ (at both the lexical and syntactic level) for the information presented before.

The priming experiments by Swinney et al. (1979) and Camblin et al. (2000) suggest that priming effects are not necessarily absent after a clause boundary. Priming effects found after a clause boundary might, however, differ qualitatively from those before the boundary. The suggestion by Swinney et al. is that priming effects within the same clause take place at the word-level (lexical-lexical priming), while priming after the clause boundary is caused by more general semantic information.

In Experiments 1 and 2, that were discussed in detail in Chapter 3, no verb priming effects were found after the conjunction, the word directly after the clause boundary which links the matrix clause to an embedded clause (Experiment 1, probe position [3] in example sentence (5), below) or a coordinating clause (Experiment 2, probe position [4] in sentence (6); conjunctions are in bold). The difference in RTs between probes related and unrelated to the matrix verb was 6 and -5 ms respectively.


These data suggest that when the information in the matrix clause has been shifted to long term memory, no priming of the verb is observed. It remains an open question, however, whether or not this pattern will be continued during the remainder of the second clause.

In this chapter three experiments will be presented: Experiment 6 was set up to test the robustness of the ‘clause boundary effect’, Experiment 3b takes a closer look at the activation of the matrix verb during the second clause, and Experiment 7 tries to discover whether activation of verb meaning always decays after the occurrence of a clause
boundary or whether the activation of the matrix verb is dependent on the duration of ‘its’ clause.

3. **EXPERIMENT 6: SOV CLAUSES**

### 3.1. Introduction

In Experiment 6, the main clause was revised such that its main verb\(^2\) appeared at the end of the clause. This was realized by inserting a modal verb at V2 position. The related probes were verbs related to the main verb. A possible priming effect of the main verb was assessed 700 ms after its offset (probe position [3] in (7)), which was on average 153 ms after the conjunction and 344 ms after the start of the second clause. The aim of this test position was to verify the robustness of the discontinuation effect of verb activation in the second clause. In Experiment 1, significant priming had been found 700 ms after the matrix verb when no clause boundary intervened. Therefore, an absence of verb priming after the same amount of time in this experiment would be a strong claim for an effect of the clause boundary.

### 3.2. Methods

#### 3.2.1 Participants

In total, 48 undergraduate and graduate students from the University of Groningen were paid for participation in the experiment. Two participants were excluded *post-hoc* because they did not meet the preset criteria on background characteristics (mother tongue is Dutch, self-reported normal or corrected-to-normal vision and hearing, no dyslexia or other reading problems). One participant was excluded for not following the instructions correctly. Participants were further excluded from the final analyses if their error score on the lexical decision task was higher than 10%, if the mean or SD of their reaction times (RTs) deviated from the overall mean or SD by more than 2.5 SD, or if they answered less than 67% of the comprehension questions correctly. Data from four participants were excluded for these reasons.

The remaining 41 participants (4 male, 37 female) were right-handed, native speakers of Dutch. Their mean age was 21.4 years (range 18-29). The 48 original participants were randomly assigned to one of three groups, the number of participants per group for the remaining 41 participants was 13, 13 and 15.

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\(^2\) Since there are two matrix verbs (the verbs of the matrix or main clause) in this experiment, the relevant verb is referred to as *main* verb, to distinguish it from the *modal* verb.
3.2.2 Materials

Experimental sentences were of the following structure: Subject NP – modal verb – Object NP – adjunct (Adverbial Phrase of Time) – main verb – conjunction – second clause:


(lit) The little boys will the fanatical soccer-coach every Saturday[1]morning again imitate [2], because they [3] want later all pro-soccer-player(s) to-become.

NADOEN (COPY) - FILMEN (FILM)

The related and control probes used were the same as in Experiments 1, 2 and 4. Probes were presented at three different positions: probe position [1] was placed 700 ms after the onset of the adjunct (i.e., after both arguments have occurred), probe position [2] at the offset of the main verb (the distance between probe position [1] and [2] was on average 1240 ms), and probe position [3] 700 ms after probe position [2], on average 153 ms after the offset of the conjunction.

There were 41 experimental sentences and 42 pseudo-experimental sentences (sentences with the same structure as the experimental sentences). The pseudo-experimental fillers were combined with non-words, to prevent any correlation between sentence type and response type (word/non-word). In addition, 20 filler sentences of different structures (10 words, 10 non-words) were added. To ensure that participants paid attention to the sentences, comprehension questions were formulated for 15 sentences throughout the experiment (15% of the sentences).

3.2.3 Design and procedure

The design and procedure were the same as in previous experiments.

3.3. Results and discussion

Descriptive and inferential statistics were performed on the resulting data precisely as in previous experiments. Error rates were low (2.0%) and equally distributed across related and control probes and across probe positions. The exclusion of errors and outliers (all values deviating from the subject and item mean with more than 2.5 SD were excluded) resulted in 3.4% data loss.

The mean RTs for all probe positions and probe types are presented in Table 1. Both subject- and item-based ANOVAs revealed a significant main effect of probe type
At probe position [1] significantly faster RTs are found for probes related to the main verb than for control probes: $t_1 (40) = 3.27, p = .001; t_2 (40) = 1.79, p = .041$. However, a closer look at the data revealed that this ‘predictive’ priming effect is caused by a methodological artefact\(^3\). Since all participants heard the same sentences twice (with at least two weeks in between the two sessions) a memory effect could have affected the performance in the second session. After hearing a large part of the matrix clause (probe position [2] occurred after the occurrence of the Subject NP, modal verb, Object NP and part of the adjunct) it might well be the case that the participants anticipated (implicitly or maybe even explicitly) the clause-final verb\(^4\). This alternative explanation was tested in a session analysis: the previous analyses were run for session 1 and session 2 apart. The results were clear: In session 1, the difference between RTs for related and control probes at probe position [1] was 3 ms, in session 2 it was 27 ms.

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\(^3\) I am greatly indebted to Frank Wijnen who pointed this out.

\(^4\) Although the design was similar in all experiments described in this dissertation, in previous experiments probe positions were always presented after the occurrence of the verb, and therefore priming caused by a ‘memory trace’ of the verb is not a plausible alternative explanation for any priming effects that were demonstrated before. The exception is probe position [1] in Experiment 3, however, only very little information had been presented before this position (the determiner, adjective and part of the Subject head noun) and therefore it seems not probable that any predictions were formed on the basis of this. Indeed, split-session analyses for Experiment 3 demonstrate no difference in results between session 1 and 2.
The results at probe position [2] and [3] confirm the ‘clause boundary hypothesis’: priming of the main verb was found directly after its occurrence at the end of the clause (probe position [2]: $t_1(40) = 2.99, \ p = .003$; $t_2(40) = 2.56, \ p = .007$), but dissipated after the start of the next clause (probe position [3]: $t_1(40) = 1.34, \ p = .10$; $t_2(40) = 1.27, \ p = .11$). For probe positions [2] and [3], the interaction between probe position and probe type did not reach significance ($F_1(1,40) = 2.77, \ p = .104$; $F_2(1,40) = 2.18, \ p = .148$).

As was reported above, probe position [2] in Experiment 1 was placed 700 ms after the matrix verb, and therefore can be compared with position [3] in the present experiment. A major difference between these positions is the intervening clause boundary in the present experiment. In Experiment 1, a significant priming effect of 16 ms directly after the verb was followed by a significant effect of 14 ms 700 ms later. In the present experiment, a significant difference of 24 ms at the offset of the verb was reduced to a non-significant difference of 9 ms after 700 ms (and a clause boundary). Although the interaction effects were not significant in the present experiment, it does not seem tenable to completely disregard the decrease in priming. On the basis of the bare numbers and the $t$-tests, it is tentatively concluded that, even when the probe is presented only 700 ms after the verb (that is, the prime), no priming effect is found after an intervening clause boundary.

4. THE SECOND CLAUSE IN MORE DETAIL: EXPERIMENT 3B

4.1. Introduction

Experiment 3b is an extension of Experiment 3 (Chapter 4). The main question to be answered with this experiment is whether the clause (boundary) effect is long-lived, or is only a temporary effect. If priming of the matrix verb only temporarily comes to a halt after the conjunction this would suggest that it is not a ‘real’ clause effect, but rather, for example, a consequence of processing overload around the clause boundary. This experiment was also meant to replicate the clause boundary effects found in Experiments 1, 2 and 7, where transitive verbs were used, with another set and type of verbs (namely intransitives).

4.2. Methods

4.2.1 Participants

Of the 47 participants that took part in the experiment, six had to be excluded for the following reasons: three participants made more than 10% errors on the LDT, one answered less than 67% of the comprehension questions correctly, one participant failed
both these criteria, and two participants had RTs of which the mean or SD deviated more
than 2.5 SD from the other participants. The remaining 41 participants (5 male, 36 female)
were right-handed (1 ambidextrous) native speakers of Dutch (7 Dutch-Frisian bilinguals).
Their mean age was 21.3 years (range 18-30 years), and they reported normal or corrected-
to-normal vision and hearing, no dyslexia or other reading problems and no history of
neurological disorders or long periods of unconsciousness.

4.2.2 Materials

Experiment 3b employed the same materials as Experiment 3, but three new probe
positions were selected: probe position [4] was placed at the end of the matrix clause and
probe position [5] 700 ms later, which was on average 414 ms after the start of the second
clause. These two probe positions mirrored the test positions in Experiments 2 and 7.
Probe position [6], finally, was placed another 700 ms later, so on average 1114 ms after the
onset of the second clause.

(8) De hoge politiefunctionarissen ontbijten in de rustige intercity naar Den Haag [4],

The senior police-officers are-having-breakfast in the quiet intercity-train to The Hague [4], while

ETEN (EAT) – LEVEN (LIVE)

4.3. Results

The exclusion of errors (2.7%) and outliers (1.2%) resulted in 3.9% data loss. The
differences in RTs between related and control probes (priming effect) decreased from the
end of the main clause until position [6], 1400 ms later (see Table 2).

There was a main effect of probe type, which was significant in the subject analysis (F1
(1,40) = 14.08, p = .001), but only marginally so in the item analysis (F2 (1,35) = 2.89, p = .098). There were no other main effects and no significant interactions. Planned
comparisons per probe position showed that the priming effect was significant at probe
position [4] (t1 (40) = 2.74, p = .005; t2 (35) = 1.73, p = .046), and not at probe position [5]
(t1 (40) = 1.58, p = .061; t2 (35) = 1.36, p = .094) and [6] (t1 (40) = 1.03, p > .15; t2 (35) =
0.97, p > .15).
Table 2. Mean (and SD) reaction times to related and control probes for each probe position in Experiment 3b.

<table>
<thead>
<tr>
<th>Probe Type</th>
<th>Probe Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>684 (123)</td>
</tr>
<tr>
<td>Related</td>
<td>662 (117)</td>
</tr>
<tr>
<td>Difference</td>
<td>22 **</td>
</tr>
</tbody>
</table>

** p<.01 (paired samples t-test, subject-analyses, 1-tailed)


4.4. Discussion

Experiment 6 and Experiment 3b replicate and extend earlier findings concerning the effect of the matrix verb at and after the end of the main clause. First of all, although priming of the verb was found 700 ms after its presence when both the verb prime and the probe were presented during the main clause (Experiment 1, probe position [2]), a clause boundary intervening between the verb and the probe resulted in an important decrease in priming (Experiment 6, probe position [3])

Secondly, this decrease in priming or absence of priming of the matrix verb was found at a position more than a second into the next clause as well. Therefore, it seems safe to conclude that the matrix verb remains ‘inactive’ during the remainder of the second clause.

An important question left unanswered until now is whether it is the clause boundary per se, or rather the clause of which the verb forms the core, that affects the priming pattern. Possibly, the activation of the matrix verb does not necessarily vanish upon encountering a clause boundary, but this is only the case if the boundary signals that the main clause ends. This hypothesis will be tested in a further experiment, where an embedded clause is inserted within the main clause.

An abrupt end of the activation of the verb meaning cannot be claimed on the basis of the data: a significant interaction effect between the final probes in the main clause and the first probe in the second clause was only found in Experiment 2, but not in Experiments 1, 3b and 6.
5. A CENTER-EMBEDDED CLAUSE

5.1. Experiment 7a

5.1.1 Introduction

In Experiment 7a the following issue is addressed: What happens at a clause boundary that occurs while the main clause has not been finished yet? By studying sentences in which the main clause is interrupted by a center-embedded relative clause, it can be tested what matters for priming of the matrix verb: whether or not the clause has ended, or whether or not a clause boundary occurs.

Is it the case that the activation of the verb always dissipates when another clause is encountered? If so, then this should also be the case when the main clause has not been finished yet, resulting in an absence of priming effects of the matrix verb in an embedded clause. A reason for this might be that in a new clause a new verb ‘governs’ (either syntactically or semantically) the new sentence constituents, so the current verb is not relevant anymore (or the new verb interferes with the activation of the other). Alternatively, it could also be the case that activation of the matrix verb only ends at the end of the main clause. In this case, continued priming is expected during the center-embedded material, as the main clause does not end at the start of the second clause in this case.

5.1.2 Method

5.1.2.1 Participants

Forty-two students of the University of Groningen took part in the experiment. Two participants were excluded post-hoc (one person failed the comprehension question criterion of 67% correct answers, the other person was excluded because both the mean and SD of the RTs exceeded the mean and SD averaged over all participants by more than 2.5 SD). No participants made more than 10% errors on the Lexical Decision Task.

The remaining 40 participants (1 male, 39 female) were all right-handed (2 ambidextrous) native Dutch speakers (4 were raised bilingually Dutch-Frisian) with a mean age of 20.8 (range 18-29) years, self-reported normal or corrected-to-normal vision and hearing, no dyslexia or other reading problems and no history of neurological disorders or long periods of unconsciousness. The 40 participants were divided in two groups of 20 participants each.

5.1.2.2 Materials

Forty experimental sentences (see (9)) were constructed with the following structure: adjunct – verb – Subject NP – Subject-relative clause – continuation of main clause. The
first adjunct was a prepositional phrase of time consisting of four to six syllables. The Subject NP always consisted of a determiner, an adjective and a noun and was six to seven syllables in length. The Subject-relative clause was 13 to 15 syllables long. The continuation of the main clause, consisting of an adjunct and an Object NP, was 12 to 14 syllables in length and not subject to any further restrictions. All words in the sentence were unrelated to the matrix verb, the related and control probe and to the main verb of the embedded clause.

The matrix verb and the verb of the embedded clause were both part of the list of prime verbs used in Experiments 1 to 3.\textsuperscript{6} Related probes (that is, probes related to the matrix verb) and control probes were also copied from this list. Probes were presented at two positions: probe position [1] was placed 1000 ms after the start of the embedded relative clause and position [2] after the verb of the embedded clause (or, more precisely, at the onset of the first word after the verb of the embedded clause). Position [1] was inserted to measure whether the activation of the meaning of the matrix verb dies out after the start of a new clause. A delay of 1000 ms was chosen to be on the safe side, since it is known from previous experiments that the verb remains activated at least until the clause boundary, and it was hypothesized on the basis of the literature that deactivation might be slowed down for verbs (see Chapter 5). The objective for position [2] was to find out more about the pattern of verb activation during the embedding, and whether the introduction of a new verb has an effect on the activation of the matrix verb.

Per experimental session, 20 experimental sentences were used, to prevent repetition of verbs. Thirty filler sentences were composed. Of these, 20 sentences had a similar structure and were combined with non-word probes, and ten had varying structures and were combined with either word probes (five) or non-word probes (five). Thus, the word:non-word ratio was 1:1. Probe placement was varied across the filler sentences. The sentences were presented in combination with 82 sentences from Experiment 3b (which contained different sentence types and mostly intransitive verbs). In total, 30 comprehension questions were asked throughout the experiment, to encourage participants
to pay attention to the sentences. Participants answering less than 67% of these questions correctly were excluded from the analyses.

5.1.2.3 Design

The 40 prime verbs were divided into 20 pairs. Two sentences were constructed for each pair: if a verb was the matrix verb in sentence A, it was the verb of the center-embedded clause in sentence B, and vice versa. For the present experiment, one sentence of each pair was selected, resulting in 20 sentences. These 20 sentences were chosen such that they were matched with the remaining 20 sentences on all important background characteristics of the probes (see Chapter 3, section 3.2.2). Within these sentences, half of the probes were presented at probe position [1] and the other half at probe position [2]. Furthermore, per probe position, half of the probes were related probes and half were control probes. For each list, a parallel list was then constructed in which related and control probes were swapped. In the present experiment, a list and its parallel list were administered in two sessions with at minimal interval of two weeks. Thus, each participant heard the same sentences twice, saw probes at both probe positions and was presented with both related and control probes.

5.1.2.4 Procedure

The procedure was the same as in the previous experiments.

5.1.3 Results

Descriptive and inferential statistics were performed on the resulting data precisely as in the previous experiments. Exclusion of errors (2.4%) and outliers resulted in 3.1% data loss. Table 3 presents the results for this experiment.

In general, responses to related probes were faster than to control probes, resulting in a main effect of probe type ($F_1$ (1,39) = 14.07, $p < .001$; $F_2$ (1,18) = 4.57, $p = .047$). There was no significant interaction between probe position and probe type ($F_1$ (1,39) = .43, $p > .5$; $F_2$ (1,18) = 1.38, $p > .2$). *A priori* planned comparisons demonstrate that the priming effect is significant at the first probe position examined ($t_1$ (39) = 3.25, $p = .001$; $t_2$ (19) = 2.43, $p = .013$), but not (or only marginally) at probe position [2] ($t_1$ (39) = 1.61, $p = .057$; $t_2$ (18) = 1.34, $p = .099$).

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6 The underlying idea was that the same materials could be used in a follow-up experiment testing the activation pattern of the main verb of the embedded clause, allowing for a more detailed observation of verb behavior in these types of sentences.
Table 3. Mean (and SD) reaction times to related and control probes for each probe position in Experiment 7a.

<table>
<thead>
<tr>
<th>Probe Type</th>
<th>Probe Position</th>
<th>[1]</th>
<th>[2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>688 (112)</td>
<td>681 (121)</td>
<td></td>
</tr>
<tr>
<td>Related</td>
<td>659 (114)</td>
<td>663 (118)</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>28 **</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

** p<.01 (paired samples t-test, subject-analyses, 1-tailed)

Voor de beklimming ontslaan de sterke bergbeklimmers, die in het basiskamp [1] het laatste weblog schrijven [2], volgens afspraak alle ingehuurde sherpa’s.

Before the climb fire the strong mountaineers, who in the base-camp [1] the final web-log are-writing [2], according-to (the) agreement all hired sherpas.

5.1.4 Discussion

The data show that the activation of the matrix verb does not automatically dissipate upon encountering a new clause. One second after the start of an embedded subject-relative clause a significant priming effect was found. At the end of the embedding, after the introduction of the clause-final main verb, this priming effect was reduced. Whether this reduction is caused by a general decrease in priming throughout the embedding, or a more abrupt deactivation of the verb caused by competition with another verb cannot be concluded on the basis of these data.7

5.2. Experiment 7b

5.2.1 Introduction

An important question left unresolved after the previous experiments is what happens with the matrix verb when the main clause is continued after the center-embedding. Using the same materials, but a different group of participants, this question was tackled by inserting a probe 1000 ms after the start of the continuation of the main clause:

7 Conversely, it could be the case that the marginal effect found after the verb in the embedding appears just because of the presence of this verb, assuming some sort of word class or structural/syntactic priming effect (both this verb and the matrix verb were transitive in all sentences).
Voordat de beklimming ontslaan de sterke bergbeklimmers, die in het basiskamp het laatste weblog schrijven, volgens afspraak [3] alle ingehuurde sherpas.

Before the climb fire the strong mountaineers, who in the base-camp the final web-log are-writing, according-to (the) agreement [3] all hired sherpas.

5.2.2 Method

5.2.2.1 Participants

Since probes were presented at only one probe position, the amount of items per participant was doubled in this experiment. Therefore, the number of participants could be relatively low. Nine participants were initially tested, of whom one had to be excluded because the mean RTs deviated more than 2.5 SD from those of the other participants (this was analyzed for the two groups of participants in Experiments 6a and 6b together). The remaining 8 participants (all female) were all right-handed native Dutch speakers (1 person was raised bilingually Dutch-Frisian) with a mean age of 21.0 (range 18-23) years, self-reported normal or corrected-to-normal vision and hearing, no dyslexia or other reading problems and no history of neurological disorders or long periods of unconsciousness.

5.2.2.2 Materials, design, and procedure

The materials and the procedure were the same as in Experiment 6a, with the only difference that only one list with its counterpart was needed and thus all participants were presented with exactly the same materials. Half of the experimental sentences were combined with related and half with control probes and this was reversed in the parallel list. All participants were tested twice and the order in which the two lists were presented was counterbalanced.

5.2.3 Results

Exclusion of errors (3.4%) and outliers resulted in 4.7% data loss. The difference in RTs between related and control probes was significant ($t_1 (7) = 3.00, p = .01; t_2 (19) = 2.27, p = .018$).
Table 4. Mean (and SD) reaction times to related and control probes for each probe position in Experiment 7b.

<table>
<thead>
<tr>
<th>Probe Type</th>
<th>Probe Position</th>
<th>[3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>669 (140)</td>
<td></td>
</tr>
<tr>
<td>Related</td>
<td>638 (130)</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>31 *</td>
<td></td>
</tr>
</tbody>
</table>

*p<.05 (paired samples t-test, subject-analyses, 1-tailed)

Voor de beklimming ontslaan de sterke bergbeklimmers, die in het basiskamp het laatste weblog schrijven, volgens afspraak [3] alle ingehuurde sherpa’s.

Before the climb fire the strong mountaineers, who in the base-camp the final web-log are-writing, according-to (the) agreement [3] all hired sherpas.

5.2.4 Discussion

The current data in combination with the data from Experiment 7a indicate that 1000 ms after the main clause was continued, the activation of the matrix verb is back again at a level comparable to 1000 ms after the start of the embedding. In between, a relapse in the activation level of the matrix verb was present after the occurrence of the clause-final verb in the embedded relative clause.

6. GENERAL DISCUSSION

The pattern of verb priming found in Experiments 1 and 2 (Chapter 3) resulted in the hypothesis that activation of the verb always ends after a clause boundary. In this chapter, the significance of the clause boundary was once again established in Experiment 6, which employed verb-final main clauses. This experiment showed deactivation of the verb once a clause boundary was encountered within a time period as short as 700 ms. The question about the effect of the clause boundary on activation of the matrix verb was further tackled from two directions. The first track highlighted the activation pattern of the meaning of the matrix verb during a second clause following the main clause, the second one investigated priming during an embedded clause which interrupted the main clause (center-embedding). Results from both tracks taken together suggest that the clause boundary is not an all-or-none phenomenon. Priming of the matrix verb is absent after a clause boundary linking the main clause with a second clause. However, when an embedded clause interrupts the main clause, the priming pattern does not end with the occurrence of the clause boundary. The verb priming effect is strongly present when the first clause
boundary has been crossed (to ‘enter’ the center-embedded clause), and this is again the case after the second clause boundary crossing (after which the main clause continues). Only at the end of the center-embedding, when a new verb is introduced, is the effect temporarily reduced.

Thus, it seems to be the case that the verb activation pattern is not so much related to the occurrence of a clause boundary, rather, it is closely linked to the clause of which this verb forms the core. The meaning of the matrix verb is activated during the entire main clause, even when a different clause is inserted within this clause. When the main clause is finished, and a new clause follows, the activation is absent after the conjunction signalling the start of this new clause and remains absent during the rest of the clause.

Whereas Swinney et al. (1979) found that semantic priming is unaffected by the presence of a clause boundary intervening between the prime and the probes, the matter seems to be a bit more complicated for verbs: the relation between the matrix verb and ‘its’ clause seems to be essential. When the main clause is finished, the verb does not function as a prime during later parts of the sentence. However, when the main clause is only temporarily interrupted, the verb continues to exert influence, probably to stay associated with its event. This is in line with the literature reviewed above: once a clause is completed, information derived from that clause is shifted from working memory.