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The Time Course of Verb Processing in Dutch Sentences

Dieuwke de Goede · Lewis P. Shapiro · Femke Wester · David A. Swinney · Roelien Bastiaanse

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Abstract The verb has traditionally been characterized as the central element in a sentence. Nevertheless, the exact role of the verb during the actual ongoing comprehension of a sentence as it unfolds in time remains largely unknown. This paper reports the results of two Cross-Modal Lexical Priming (CMLP) experiments detailing the pattern of verb priming during on-line processing of Dutch sentences. Results are contrasted with data from a third CMLP experiment on priming of nouns in similar sentences. It is demonstrated that the meaning of a matrix verb remains active throughout the entire matrix clause, while this is not the case for the meaning of a subject head noun. Activation of the meaning of the verb only dissipates upon encountering a clear signal as to the start of a new clause.

Keywords Cross-modal lexical priming · Verbs · Sentence comprehension · Dutch

Introduction

Verbs are the core of a sentence: they express the event or activity that the sentence describes, the moment in time at which that event or activity takes place, and they provide the relation between the possible persons and objects involved in the event. Thus, verbs provide bridges between nearly all aspects of sentential processing. Because of this key role of verbs, accounts of sentence processing have long acknowledged a need for explicit details of verb

D. de Goede · F. Wester · R. Bastiaanse
University of Groningen, Groningen, The Netherlands

L. P. Shapiro
San Diego State University, San Diego, CA, USA

D. A. Swinney
University of California, La Jolla, San Diego, CA, USA

D. de Goede (✉)
Max Planck Institute for Psycholinguistics, P.O. Box 310, 6500 AH Nijmegen, The Netherlands
e-mail: dieuwke.degoede@mpi.nl

activation and integration. From the earliest accounts of sentence perception (e.g., Fodor et al. 1968) to the most current ones, studies revealing the properties of verbs have played increasingly important roles in informing language processing models. Interestingly, while research over the years has demonstrated that verb information plays a crucial role in sentence processing, there remains a surprising paucity of evidence detailing the precise nature of how and when such information is employed. For example, it is well established that when verbs are encountered during sentence processing, their argument structure configurations and thematic properties are immediately activated (Bock 1986; Ferretti et al. 2001; Pickering and Branigan 1998; Shapiro et al. 1987, 1989; Trueswell and Kim 1998). However, only a few details are known about the role of the verb throughout the ongoing integration of sentential material prior to final sentence interpretation. The work presented in this paper aims to fill part of this void, with the specific goal of detailing the nature of activation of verbs throughout the process of sentence comprehension.

Linguistic Background

In the standard linguistic analysis, Dutch is assumed to be a Subject-Object-Verb (SOV) language (Koster 1975). All non-finite verbs, and in embedded clauses both finite and non-finite verbs, occur in clause-final position:

(1) Julia wil het boek lezen.
Julia wants the book (to) read.
(Julia wants to read the book.)

(2) ..., omdat Julia het boek wil lezen.
..., because Julia the book wants to read.
(..., because Julia wants to read the book.)

In Dutch declarative matrix clauses - the type of sentences that will be used in our experiments - the verb appears in second position, after the first constituent (3). The word order in the matrix clause is derived from the word order in the embedded clause (Koster 1975). The finite verb, therefore, is said to have 'moved' from its base position at the end of the clause to second position. This rule is called *Verb Second* (V2). Here we depict the 'movement' of the verb through *copy-and-delete* (following Adger 2003; Chomsky 1995) whereby constituents are represented by a copy at the position from where they move, and then deleted before interpretation. Example (3) shows Dutch matrix clauses with the verb in second position. For clarification purposes the base position of the verb is indicated by the verb between angled brackets.

(3) a. Julia leest het boek <~~leest~~>.
Julia reads the book <~~reads~~>.
(Julia reads the book.)
b. Vandaag leest Julia het boek <~~leest~~>.
Today reads Julia the book <~~reads~~>.
(Today Julia reads the book.)

Thus, the V2 phenomenon of Dutch matrix clauses allows us to study the on-line activation pattern of verb meaning in an interesting linguistic 'environment', that is, in the presence of an abstract copy of the verb in the sentence's underlying form at the end of the clause. What might be the consequences of this representation for Dutch sentence processing? Possible answers to this question come from a number of on-line sentence processing studies in different languages.

Psycholinguistic Background

While there is not much evidence on the consequences of verb movement for sentence processing, many experiments have been conducted in which the copied constituent was a *wh*-phrase. Consider an early experiment by Swinney et al. (1988, reported in Nicol and Swinney 1989), who presented participants with spoken sentences like:

(4) The policeman saw the boy who the crowd at the party accused <~~the boy~~> of the crime.

Since *the boy* is the direct object of *accused*,[1] and English is an SVO language, the base position of *the boy* immediately follows the verb *accused*. Therefore, it is assumed that a copy of *the boy* is postulated after *accused* and then deleted from the representation before final interpretation. This position of the deleted *wh*-phrase is called the *gap*.

The Cross-Modal Lexical Priming (CMLP) paradigm (Swinney et al. 1979) was used to probe for activation of the meaning of the direct object during the unfolding sentence. While listening to the sentences, participants had to make a lexical decision to visual probes presented at particular points during each sentence. These probes were either related to the direct object, unrelated control probes matched to the related ones or non-words. Swinney et al. (1988, reported in Nicol and Swinney 1989) found shorter reaction times for the probes related to the dislocated direct object (e.g., *child*) than for the control probes (e.g., *chimp*) when the probes were presented at the base position of *boy,* directly after the verb *accused*. This was interpreted as a priming effect. Importantly, no priming effect was found at an intermediate control position before the verb.

These results provide us with two important check points for comparison with the verb data that we will be presenting. At some point after its occurrence in a sentence, the meaning of a displaced noun is first *de-activated*, to be *re-activated* at the site of the copy (gap). With respect to the first check point—the duration of activation immediately after the occurrence of the word—studies on anaphora and *wh*-movement have repeatedly demonstrated that activation of the meaning of anaphors and *wh*-constituents degrades quite rapidly. According to Featherston (2001), the existing data converge on a figure of about 500 ms. As for the second check point—reactivation of the displaced constituent at the site of the gap—similar gap-filling effects for displaced NPs (mainly *wh*-phrases) have been demonstrated with a number of methodologies in English and other languages such as German, Japanese,[2] and Bulgarian (see, e.g., Bever and McElree 1988; Clahsen and Hansen 1997; Felser et al. 2003; Fiebach et al. 2001; Hickok 1993; Love and Swinney 1996; Muckel and Pechmann 2002; Nagel et al. 1994; Nakano et al. 2002; Nicol and Swinney 1989; Stamenov and Andonova 1998; Stowe 1986; Tanenhaus et al. 1989).

In conclusion, the activation of the meaning of a displaced noun has been found to be relatively short-lived, but has consistently been boosted at the occurrence of the gap. It is, however, unknown how long a verb remains activated after its occurrence in a sentence, and whether a verb that is not in its base position is also reactivated at its original position.

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[1] Strictly speaking, the direct object of *accused* is *who*, but the authors assume that *who*, because of its co-reference with *boy*, has inherited the semantic characteristics of *boy*.

[2] Whereas the original Swinney et al. (1988, reported in Nicol and Swinney 1989) data are also consistent with a model where the filler associates directly with the verb's argument structure (Pickering 1993; Traxler and Pickering 1996), this is not the case for the German and Japanese data (both being verb final languages). In the 'direct association' models the reactivation findings would involve identifying a verb and associating the filler directly with an unsaturated position in the argument structure of the verb.

Processing Verbs

One issue that may affect the activation pattern of the verb during on-line sentence comprehension is the fact that the verb is at the core of a sentence and 'governs' both the semantic and syntactic information in a sentence. Verbs have important relations with the other word categories in a sentence: for example, adverbs modify verbs, the verb introduces prepositional phrases, and with respect to nouns, the verb provides the number of entities (persons or objects) involved in the event (argument structure), the types of syntactic entities (subcategorization frame) and the relation between these entities and the verb itself (theta role assignment). The verb plays a major semantic role as well: it expresses the event that the sentence describes (by its proper meaning).

Psycholinguistic studies suggest that these differences between nouns and verbs matter during sentence processing: many studies have revealed that, in isolation, verbs take longer to process than nouns (reaction times to verbs are longer than to nouns: Gomes et al. 1997; Haan et al. 2000; Rösler et al. 2001) and effects of argument structure have been found at very early stages in sentence processing (e.g., MacDonald et al. 1994; Shapiro et al. 1991, 1987, 1989; Trueswell and Kim 1998). It is unknown what role these characteristics of verbs play during on-line processing of (moved) verbs. Will the activation of the meaning of the verb be as short-lived as that of nouns? Will similar reactivation effects be found for verbs that are displaced from their base positions?

One clue comes from work investigating VP-ellipsis in English. In a series of experiments, Shapiro, Hestvik, and colleagues (Shapiro and Hestvik 1995; Shapiro et al. 2003) found reactivation of an NP (*a tie*) that is part of a verb phrase (*bought a tie for Easter*) at an elided position in an ellipsis structure. In (5) there is an elided VP in the coordinate clause, signalled by the bare auxiliary *did*, that receives its reference from the VP in the matrix clause. Using CMLP, Shapiro et al. found that the direct object from the matrix clause (*a tie*) was reactivated at the elided position [2] in the coordinate clause (no activation was observed at the pre-ellipsis position [1]).

(5) The mailman [bought a tie for Easter], and his brother, who was playing volleyball, did <~~buy a tie for Easter~~> too, according to the sales clerk.
(6) The mailman bought a tie for Easter, and his brother, who was play[1]ing volleyball, did [2] too, according to the sales clerk.

Though only activation of the NP was tested in this case, it was assumed that the *verb* from the matrix clause was also reactivated, given that the entire VP is copied. This latter assumption was directly tested in a follow-up study (Callahan et al., submitted). Surprisingly, the priming pattern of the verb was found to deviate importantly from the reactivation pattern for nouns (as part of the VP presumably being copied) presented above. Callahan et al. found activation of the verb when it was first encountered in the antecedent clause, and this activation dissipated when tested at approximately 1200 ms downstream from the verb, still in the first clause. Immediately after the conjunction in the ellipsis clause, verb activation reappeared and was maintained through the elided position.

There are two relevant points to the Callahan et al. work for the present study. First, the verb, once active in the antecedent clause, does not remain active throughout that clause. Though this is similar to patterns found for noun activation in canonical constructions (e.g., Subject-Verb-Object), it may be the case that the verb remains activated longer than what is observed for nouns. Second, in the ellipsis clause the verb appears to be active throughout, at least until the elided position. This verb activation pattern is unlike what is found for NPs in ellipsis, where they are only found to be reactivated from the antecedent clause to the elided position. It is possible that this activation pattern, at least in Callahan et al., was due to the well-known "parallelism effect": when a conjunction or other cue signalling an elliptical form occurs, the processing system prefers the structure to parallel that of the preceding clause. Whatever the explanation for Callahan et al., it is clear that verb activation patterns may be unlike those seen for NPs.

The Current Study

The aim of the current study is to investigate the activation pattern of verbs throughout the unfolding sentence, and to compare it to the pattern for nouns. All Dutch sentences employed contain initial matrix clauses linked with a subordinate or coordinate clause via a conjunction. According to standard linguistic analysis Dutch matrix clauses are derived from the embedded clause, rendering a copy of the displaced verb at the end of the clause. The CMLP paradigm was used to lay down the temporal characteristics of the activation pattern of verb processing in Dutch matrix clauses by measuring the priming effect of the verb at various positions throughout the sentence.

The following verb priming patterns may show up:

1. If the linguistic phenomenon of verb movement is reflected in the priming data like it is in the case of *wh*-movement, the typical 'gap-filling pattern' is expected: priming of the verb directly after its occurrence, no priming at intermediate positions later in the sentence and priming again at the end of the clause, where a presumed copy of the verb resides (that is, at the gap position).
2. If verb movement is not reflected during on-line sentence processing a 'punctuate' priming pattern (priming only directly after the occurrence of the verb and not at any of the later positions) is expected.
3. If moved verbs behave differently from moved nouns, similarly to what was found for verbs in comparison to nouns in English VP-ellipsis (Callahan et al., submitted), one of the possible priming patterns would be prolonged verb priming, possibly in combination with priming at the gap position.

Experiment 1

Introduction

The initial experiment investigates the priming of V2 positioned verbs in Dutch declarative matrix clauses. A design is used where probes semantically related to the matrix verb and unrelated control probes are momentarily presented at one of three positions throughout the sentence. Consider the following Dutch sentence (provided with English gloss) in which the verb *imiteren* (*imitate*) resides in V2 position and test positions are indicated between square brackets:

(7) De kleine jongens imiteren [1] hun fanatieke [2] rood-aangelopen voetbaltrainer <~~imiteren~~>, omdat [3] ze later allemaal profvoetballer willen worden.

The little boys imitate [1] their fanatical [2] red-faced soccer-coach <~~imitate~~>, because [3] they later all pro-soccer-player(s) want to-become.

NADOEN (*COPY*) – FILMEN (*FILM*)

Faster RTs to related (e.g., NADOEN/*COPY*) than to control probes (e.g., FILMEN/*FILM*) are predicted at position [1], shortly after the verb is encountered. This forms a baseline to demonstrate that the probes are initially primed by the verb and that the verb has been fully processed when encountered. Probe position [2] provides a key intermediate test position to examine the duration of initial activation. Test position [3] is placed at the position where the putative verb gap can be unambiguously detected from the input, that is, after the conjunction indicating initiation of the embedded clause. (To anticipate, Experiment 2 was specifically designed to provide a probe directly at the base position without a delay).

Method

Participants

In total, 44 undergraduate and graduate students of the University of Groningen participated in the experiment. Half were unpaid volunteers and half were given course credits for participation. Of these 44 participants one failed the preset criterion of 67% correct answers on the comprehension questions (see *Materials*), and two were excluded from the analysis because the mean or standard deviation of their reaction times deviated more than 2.5 SD from the group mean.

All remaining 41 participants (12 male, 29 female) were native speakers of Dutch and had self-reported normal or corrected-to-normal vision and hearing. Two persons were ambidextrous, the others were right-handed. The mean age was 22.4 years (range 18–30). The 44 original participants were randomly assigned to one of three groups.

Materials

Forty-two experimental sentences as in (7) were created. All sentences were matched for syntactic structure and composed according to the following criteria: the matrix verb was transitive and in third person plural, the object Noun Phrase (NP) was at least nine syllables in length, and the conjunctions were all subordinating. Each experimental sentence was paired with a *related* and an unrelated *control* probe word. The related probe was a verb which was a semantic associate of the matrix verb, and the control probe was not related to any word in the sentence.

The related probe words were chosen on the basis of an off-line *Association Task* involving 80 native Dutch speakers (undergraduate students from the University of Groningen, mean age 19.9 years, none of whom participated in the CMLP experiment). The participants were presented with a list of 104 verbs and were instructed to write down the first one or two *verbs* that came to mind for each item on the list. From the associated verbs provided, related verb probes were chosen based on having an association quotient[3] of .40 or higher across all participants.

Next, base RTs were collected for 64 highly related probes and 191 possible control probes (and 255 non-words) in an independent lexical decision task, with lexical decision probes presented for 300 ms in a list format. Twenty-five right-handed native Dutch speakers (mean age 20.7 years) participated in this task, none of whom participated in the CMLP experiment.

[3] The association quotient was calculated per item by counting the number of participants that wrote down the same verb (first or second answer) and dividing this number by the total amount of participants.

The final 42 related and 42 control probes were matched per pair as closely as possible on reaction time (RT), frequency (CELEX, Burnage 1990), number of letters, number of syllables and transitivity. For each pair of probes, any difference in baseline RT was always in a direction opposite to that which might be found in priming, that is, in favor of the control probe. As a result, the baseline RTs for control probes were significantly faster than those for related probes (difference = 4.1 ms, $t(41) = 5.9$, $p < .001$).

Priming of the verb was tested at three probe positions as described above. Probe position [1] occurred at the offset of the matrix verb, probe position [2] was placed 700 ms after the first probe position and probe position [3] immediately at the offset of the conjunction (on average 456 ms after the offset of the object NP at the end of the matrix clause).

Forty-two filler sentences with a structure similar to the experimental sentences were constructed and paired with non-word probes. This resulted in an equal number of *word* versus *non-word* lexical decisions for sentences with this particular structure. In addition, 20 filler sentences containing a variety of structures (all different from the experimental sentences, but of approximately the same length) were constructed. Ten of these were paired with word probes and ten with non-word probes, to ensure equal proportions of word and non-word probes. The probe positions in the filler sentences were chosen randomly to prevent participants from building expectations about the place of the probe positions.

The non-words were created by changing two letters in existing Dutch verbs (no verbs that were used as prime in the sentences or as related or control verb probes appeared in any form in these non-word probes). All non-words were orthographically and phonologically legal Dutch words. In Dutch, all regular infinitive verbs end with *–en*. This ending of the verbs was never changed.

The 110 resulting experimental and filler sentences were pseudo-randomly combined (such that no more than three sentences in a row were either experimental or filler sentences). In addition, it was ensured that there were no semantic relations between successive sentences and/or probes in the final ordering. Finally, six practice sentences with various syntactic structures were created and paired with three non-word and three word probes.

To ensure that participants paid attention to the sentences, yes/no comprehension questions were formulated for 15 sentences throughout the entire experiment (14% of all sentences). The questions focused on factual aspects of different parts of the sentences. Questions were presented aurally in a different voice (female instead of male) and asked about both experimental and filler sentences. A comprehension question was never directly followed by an experimental sentence.

Design

Probe position and probe type were both within-subject factors. Since each experimental sentence was combined with two pairs of probes at three different probe positions, three pairs of lists were extracted from the basic pseudorandom list. Lists were completely counterbalanced such that each participant was presented with probes at all three probe positions and with both related and control probes. The three list pairs were presented to three different participant groups (see *Participants*). The two lists of one pair were presented to a participant in two different sessions at least two weeks apart, therefore, priming effects could be calculated completely within subjects.

Procedure

Participants were tested individually in a sound-attenuated room with no visual distractions. The sentences were presented over headphones with an inter-trial interval of 1500 ms. The probes were presented on a standard computer screen in lower-case *Arial* 16 point characters (white on black background). The experimental software *Tempo* (University of California, San Diego), combined with a response box with two response buttons, was used to present the auditory sentence and the visual probes and to register accuracy (word/non-word response) and RTs of the responses. Each probe was presented for 300 ms and a response was accepted up to 2000 ms from probe onset. Importantly, the auditory sentences continued without interruption during visual presentation of the probe.

Participants were instructed to listen carefully to the sentences and to expect comprehension questions about some sentences, immediately after their occurrence. It was emphasized that they should not memorize the sentences; merely listening to and comprehending the sentences would be sufficient to answer the questions correctly. Questions had to be answered by pressing the left button with their left index finger for ‘no’ or the right button with their right index finger for ‘yes’. Participants were further told that at some point during each spoken sentence they would see a string of letters on the screen. They were asked to decide for each of these letter strings (probes) whether it formed an existing Dutch word or not. Participants pressed the right button with their right index finger when they saw a word, and the left button with their left index finger when they saw a non-word. Participants were encouraged to respond as quickly and accurately as possible.

Both test sessions in the experiment were divided into three blocks: a practice block and two experimental blocks. Each experimental session (instructions and breaks included) lasted approximately 30 min. The second session was administered at least two weeks after the first one.

Results

Response times (RTs) for experimental items were collapsed separately across items and across subjects and repeated-measures analyses of variance were performed on means calculated for each. A priori planned comparisons were made between related and control items at each probe position (paired *t*-tests, one-tailed because no inhibition effects are expected). For the sake of completeness, ANOVAs will be presented as well. However, since we predict a significant difference at only one or two out of three probe positions we do not explicitly predict a main effect of probe type, nor do we expect to find a significant interaction effect.[4] Repeated-measures analyses of variance were run on means calculated across items and across participants, resulting in a subject-analysis (F_1, collapsed across items) and an item-analysis (F_2, collapsed across participants). Probe position ([1], [2], [3]) and probe type (related and control) were within-participants factors.

Error rates were low (1.8%). The exclusion of errors and outliers (all values deviating from the subject and item mean for the particular data point with more than 2.5 SD were excluded) resulted in 2.7% data loss.

The mean RTs for all probe positions and probe types are presented in Table 1 (the values that are presented here and in following tables are derived from the subject-analyses; the item-analyses revealed very similar data). As can be seen in Table 1, overall, the RTs to related

[4] Although a lack of interaction might at first sight seem to devaluate the findings, we do not agree that an interaction effect is necessary in all cases. The reason for this is that we expect significant effects at two positions and no effect at only one position, so the distribution of effects and no-effects is not even.

Table 1 Mean (and SD) reaction times in milliseconds in Experiment 1

Probe type	Probe position		
	[1]	[2]	[3]
Control (COPY)	633 (68)	635 (61)	626 (72)
Related (FILM)	617 (65)	621 (66)	620 (73)
Difference	16**	14**	6

** $p < .01$ (paired samples t-test, 1-tailed)
De kleine jongens imiteren [1] hun fanatieke [2] rood-aangelopen voetbaltrainer <~~imitate~~>, omdat [3] ze later allemaal profvoetballer willen worden
The little boys imitate [1] their fanatical [2] red-faced soccer-coach <~~imitate~~>, because [3] they later all pro-soccer-player(s) want to-become

probes were shorter than to control probes. This priming effect reached significance in the subject-based ANOVA ($F_1(1, 40) = 7.91$, $p = .008$) and marginal significance in the item-based analysis ($F_2(1, 41) = 3.43$, $p = .071$). There was no significant interaction between probe position and probe type overall ($F_1(2, 80) = .83$, $p > .4$; $F_2(2, 82) = .46$, $p > .6$). *A priori* planned paired t-tests examining for priming related to the verb at each of the individual probe positions revealed significantly shorter RTs for related than for control probes (priming for probes related to the matrix verb) at test position [1] ($t_1(40) = 2.53$, $p = .008$; $t_2(41) = 1.75$, $p = .044$) and at position [2] (although only marginally significant in the item-analyses at this place: $t_1(40) = 2.64$, $p = .006$; $t_2(41) = 1.40$, $p = .085$). Finally, planned comparisons at probe position [3] revealed an absence of priming for related versus control probes ($t_1(40) = .81$, $p > .2$; $t_2(41) = .82$, $p > .2$).

Discussion

This initial examination of the on-line activation of moved verbs in Dutch matrix clauses reveals an interesting pattern. Activation of the verb once it is first encountered appears to be maintained at least up to the point of the intermediate test position. However, the priming effect is dampened at the third test position in the subordinate clause.

The priming effect at the offset of the verb (probe position [1]) nicely indicates that the related probes are initially primed by the verb. The exact position of the intermediate probe (700 ms after the verb) was based upon the literature on gap-filling effects with nouns as the constituents of interest. Apparently, the meaning of a verb is not deactivated within the same short time interval. As suggested in the Introduction (and we revisit this in the General Discussion), it may be that verbs remain active longer than nouns because of the central role verbs play in the sentence's proposition. The questions that arise then are: how much longer does the verb remain active, and are there principled structural points where activation dissipates?

There is some evidence from this first experiment regarding the latter question: The absence of any priming effect at probe position [3] indicates that the presence of a supposed copy of the moved verb does not result in priming at the position where a conservative, bottom-up, parser could safely conclude that the main clause had ended (after the conjunction). However, given that the sentences were purposefully recorded with strong prosodic cues indicating the end of the matrix clause, it may well be that the parser did not encounter any ambiguities in recognizing the end of the clause. As such, even if the verb was reactivated at the gap position, this activation may have been rapidly suppressed before probe position [3], in anticipation of processing the subsequent clause. The next experiment was conducted to address this.

Experiment 2

Introduction

The aim of the second experiment was to further detail the activation pattern of the matrix verb throughout the unfolding sentence. An intermediate probe position 1500 ms after the occurrence of the verb and a probe position at the exact gap position were inserted as a final test for verb reactivation.

The sentences used were largely similar to the sentences in Experiment 1, with two major differences. First, the sentence part immediately following the matrix verb was extended with a temporal Adverbial Phrase so that probes could be presented 1500 ms after the onset of the verb (in contrast to the 700 ms offset employed in Experiment 1). Second, a coordinate clause rather than a subordinate clause followed the matrix clause in order to reduce any potential delay in gap-filling effects because of the subordinating conjunction (Shapiro and Hestvik 1995).

Example (8) displays a sentence and the probe positions employed for this experiment (note that *because* has two Dutch counterparts, namely *want* and *omdat*; when *omdat* is used, the second clause is subordinating, when *want* is used it is coordinating).

(8) De beschaafde mannen imiteren [1] regelmatig hun hysterisch [2] kijvende vrouwen <~~imiteren~~> [3], want [4] zo kunnen ze uiting geven aan hun frustratie zonder gewelddadig te worden.

The refined men imitate [1] regularly their hysterically [2] scolding wives <~~imitate~~> [3], because (coordinating) [4] in-this-way can they expression give to their frustration without violent to get.

NADOEN (*COPY*) – FILMEN (*FILM*)

Method

Participants

Sixty students of the University of Groningen were paid for their participation in the experiment. None of them participated in Experiment 1 or any of the pretests. Three participants were excluded because their mean and/or SD reaction time exceeded those of the overall group by more than 2.5 SD. The remaining 57 participants (12 male, 45 female) were all right-handed (one ambidextrous) native Dutch speakers with self-reported normal or corrected-to-normal vision and hearing. Their mean age was 20.7 years (range 18–28 years).

Materials

In this experiment, primes and probes for the experimental sentences were a (slightly smaller) subset of those used in Experiment 1. Since four probe positions were employed in this experiment, all materials were counterbalanced across four lists and 40 experimental sentences were selected from the 42 employed in Experiment 1. The sentences differed in a number of ways from the ones used in the previous experiment: whereas in Experiment 1 the object NP in the experimental sentences consisted of at least nine syllables, in the present experiment an adverbial phrase was added; this phrase plus the object NP was at least 12 syllables in length. Also, the second clause always started with a coordinate conjunction; half of the sentences employed *maar* (*but*), the other half *want* (*because*). The materials from each of the four probe conditions were equally distributed (counterbalanced). The number of similarly structured filler sentences (which also had an adverbial phrase in front of the object NP, to match the experimental sentences) was reduced to 40 as well, and the same non-word probes were used as in Experiment 1.

The first probe position occurred at the offset of the matrix verb. The intermediate position [2] was placed 1500 ms after the verb (and at least 700 ms before the end-of-clause verb base position to avoid end-of-sentence effects which might obscure gap-filling (see, e.g., Balogh et al. 1998). Probe position [3] was placed at the offset of the object head noun (immediately at the putative verb gap). Finally, a fourth probe position was inserted at the offset of the conjunction (i.e., in the coordinate clause), in order to evaluate whether the dissipation of matrix verb activation in the second clause generalizes to other clause/conjunction types (see (8) above for an example of probe positions).

Filler sentences were the same as in Experiment 1. One experimental session contained 40 experimental sentences, 40 filler sentences with similar structures (combined with non-words), 20 filler sentences with varying structures (combined with ten words and ten non-words) and 15 comprehension questions.

Design and Procedure

The design and procedure of this experiment were identical to those in Experiment 1.

Results

Errors and outliers were excluded from further analyses, resulting in 3.1% data loss.

Repeated measures ANOVAs revealed a main effect of probe type (priming for probes related to the matrix verb) in the subject-analysis ($F_1(1, 56) = 4.61$, $p = .036$) but not in the item-analysis ($F_2(1, 39) = .98$, $p > .3$). The overall interaction of probe type and probe position reached marginal significance ($F_1(3, 168) = 2.46$, $p = .065$; $F_2(3, 117) = 2.40$, $p = .072$).

Planned comparisons examining for priming at each probe position demonstrated no priming effect at probe position [1] ($t_1(56) = .15$, $p > .4$; $t_2(39) = .29$, $p > .3$). There was a significant effect of priming for related versus control probes at probe position [2] in the subject-based comparison ($t_1(56) = 2.49$, $p = .008$); the item-analysis at this probe position revealed a trend for priming ($t_2(39) = 1.37$, $p = .090$). Critically, a significant effect of priming for related versus control probes was found at the gap probe position [3] for both subject- and item-analyses: $t_1(56) = 2.08$, $p = .021$; $t_2(39) = 1.76$, $p = .043$. Finally, examination at the final probe position [4], following the coordinating conjunction in the embedded clause, again failed to reveal any effect of priming ($t_1(56) = -.98$, $p > .15$; $t_2(39) = -.95$, $p > .15$) (Table 2).

Discussion

The results of Experiment 2 allow important conclusions with regard to verb activation, reactivation, and the concept of gap-based verb activation. However, before discussion of these issues, we need to address the null effect at the offset of the verb. This result was

Table 2 Mean (and SD) reaction times in milliseconds in Experiment 2

Probe type	Probe position			
	[1]	[2]	[3]	[4]
Control (COPY)	663 (94)	671 (99)	668 (95)	666 (88)
Related (FILM)	662 (91)	657 (84)	654 (101)	672 (103)
Difference	1	15**	14*	−5

* $p < .05$ (paired samples *t*-test, 1-tailed)
** $p < .01$ (paired samples *t*-test, 1-tailed)
De beschaafde mannen imiteren [1] regelmatig hun hysterisch [2] kijvende vrouwen <~~imiteren~~> [3], want [4] zo kunnen ze uiting geven aan hun frustratie zonder gewelddadig te worden
The refined men imitate [1] regularly their hysterically [2] scolding wives <~~imitate~~> [3], because [4] in-this-way can they expression give to their frustration without violent to get

unexpected, particularly because it contradicted the results from Experiment 1 where significant priming was found at the verb position. In Experiment 2 we discovered, post-hoc, that the placement of the probes may have been the culprit for the null results. During the materials-design stage of the experiment, the offset of the verb was measured in the sound files in order to put the probe at this position. In some cases (e.g., *huren nog* = *rent still*), assimilation processes made it difficult to distinguish between the right edge of the verb and the left edge of the next word. In other cases the final consonant of the verb was deleted and the vowel assimilated into the next word, as is observed in colloquial Dutch (e.g., in *operere(n) regelmatig* = *operate regularly*). In case of ambiguities the earliest possible point where the verb and the next word connected was selected as the probe position. A *post-hoc* analysis revealed that for the majority of items (16 out of 18) that involved a probe which was presented relatively early (just before or immediately at the offset of the verb) a negative difference between RTs for the control and related probe was found, suggesting that these particular items did not show a ‘priming effect’. For the majority of items (17 out of 22) for which the probes were placed relatively late, that is, after the offset of the verb, a positive difference was found, suggesting a potential ‘priming effect’ for these particular items. This interaction between placement of the probe position and the ‘priming effect’ was significant ($\chi^2(1) = 17.4$, $p < .001$). The tentative conclusion based on this analysis is that many of the probes in Experiment 2 occurred too early, probably before the verb was fully processed, resulting in an incomplete demonstration of priming at probe position [1].

Critically relevant to the question of verb (re)activation is the finding of verb priming at both the intermediate probe position and the probe position at the end of the clause, the putative base position of the verb. These results, when combined with positions [1] and [2] from Experiment 1, demonstrate a clear case for continued activation of the verb in V2 throughout the matrix clause until the base position of the verb is reached at the end of the clause. This finding strongly suggests that there is no *re*activation of the verb at its gap position. Rather, the meaning of the verb remains active until the clause ends. Whether this is for reasons related to the the presumed existence of a ‘copy’ of the verb at this position in the sentence or whether it is driven by different processes is a question that cannot be answered at this point. We will return to this issue in the General Discussion.

Finally, the absence of priming at probe position [4], after the conjunction in the coordinate clause, replicates the findings from Experiment 1 for subordinating conjunctions (thus generalizing the effect across conjunction types). This supports the view that priming from the matrix verb is suppressed when a subsequent well-marked clause is encountered.[5] Activation of the verb encountered in the matrix clause appears to be bounded by the clause.

The final experiment was a simple CMLP experiment focusing on priming of subject head nouns. The purpose in doing so was to discover whether the effects found in the experiments on verb priming are verb-specific and not inherent to the language or the type of sentences used. In this experiment the same sentence structures were used as in the verb experiments. Finding a pattern of short-lived activation of the subject head noun in similar sentences and in the same language would confirm the specificity of the earlier findings of prolonged verb activation.

Experiment 3

Method

Participants

Thirty-three right-handed undergraduate students (5 male, mean age 22.2 years) were paid for taking part in the experiment. All participants were native speakers of Dutch. Two participants were excluded post-hoc for making more than 10% errors in the Lexical Decision Task.

Materials

Twenty-eight experimental sentences were created according to the following structure: subject NP—verb—two prepositional phrases (PPs)—secondary clause (see (9)). The subject NP always consisted of seven to eight syllables and comprised a definite article, an adjective, and a singular Agent. The verbs did not take a direct object, to exclude the possibility of inadvertent priming effects caused by other arguments of the verb. Although the existence of such effects has not been demonstrated before, studies on identifying errors in argument structure (e.g., Friederici and Frisch 2000) suggest that at each new argument, a check against the argument structure defined by the verb might occur.

The PPs were 12–14 syllables long, thus allowing ample time between the verb and the second probe position and between the second probe position and the end of the matrix clause.

(9) De gelukkige bakker [1] fietst met opgeheven [2] hoofd door de straten, omdat zijn broodjes goed verkopen.

The happy baker [1] cycles with raised [2] head through the streets, because his rolls well sell.

BROOD (*BREAD*) - DROOM (*DREAM*)

The related probes were nouns selected on the basis of a paper-and-pencil relatedness test in which 11 participants rated 63 pairs of prime words and possible related probe words (in

[5] This is buttressed by a significant change in priming effects between probe positions [3] and [4] which is expressed statistically by a significant interaction between probe position and probe type in an ANOVA run separately for these two probe positions ($F_1(1, 56) = 5.16$, $p = .027$; $F_2(1, 39) = 5.54$, $p = .024$).

combination with 35 filler pairs) on a scale of 1–10. Twenty-eight pairs with a rating score of 8 or higher were selected. Sixteen of these pairs had been created on the basis of an off-line association test similar to the one used in Experiment 1, using the same criterion of an association quotient of .40 or higher across all participants. The average rating score for these 16 items did not differ from that of the 12 other items (16 items from association test: mean rating score: 8.43 (SD = .41), 12 other items: 8.50 (SD = .24); $t(27) = .5$, $p > .5$, 2-tailed). This ensures that the degree of association between the verb pairs used in Experiments 1 and 2 was similar to the degree of association between the noun pairs (mean association quotients: verbs: .61, nouns: .58, $p > .4$ (*t*-test)). Therefore, any differences in priming effects between the findings in the current experiment and those in the previous experiments cannot be explained by a difference in the (a priori) association strength of the prime–probe pairs.

The related probes were then matched to unrelated control probes per pair as closely as possible on reaction time (as measured in an unprimed list lexical decision task performed by 24 right-handed participants), frequency (CELEX, Burnage 1990), number of letters and number of syllables.

Priming of the noun was checked at two positions in the matrix clause: directly after the noun itself, that is, at the onset of the word following the subject head noun (probe position [1]), and at 1000 ms after the verb (probe position [2]).

Design and Procedure

The design and procedure were similar to those in Experiment 1 and 2, with the only difference that for the filler sentences different probes were used in the two sessions of the experiment.

Results

Descriptive and inferential statistics were performed on the resulting data precisely as in Experiments 1 and 2. Error rates were low (1.5%) and the exclusion of errors and outliers resulted in 4.0% data loss.

The repeated measures ANOVA showed an overall effect of probe type in the subject-analysis ($F_1(1, 30) = 7.01$, $p = .013$), but not in the item-analysis ($F_2(1, 27) = 2.11$, $p = .16$). The interaction was not significant ($F_1(1, 30) = .92$, $p > .3$; $F_2(1, 27) = .70$, $p > .4$). Nevertheless, the numerical difference in RTs between control and related probes was much more pronounced at the first probe point (see Table 3) and paired-samples *t*-tests confirmed this: a significant priming effect was found at the first probe point, but not at test position [2] (probe point [1]: $t_1(30) = 2.23$, $p = .017$; $t_2(27) = 1.62$, $p = .058$; probe point [2]: $t_1(30) = 1.52$, $p = .07$; $t_2(27) = .69$, $p > .2$).

Discussion

The data show immediate priming of subject head nouns after their occurrence, but no priming at a position halfway through the clause. Although the discontinuation of priming is not corroborated by a significant interaction in the ANOVA, the pattern is clearly different from the continued activation pattern measured in the same time frame for matrix verbs in Experiments 1 and 2. The pattern of deactivation of nouns after their presentation is in line with English and German studies on *wh*-movement (see *Psycholinguistic Background*).

Table 3 Mean (and SD) reaction times in milliseconds in Experiment 3

Probe type	Probe position	
	[1]	[2]
Control (BREAD)	640 (130)	637 (130)
Related (DREAM)	620 (105)	627 (128)
Difference	20*	9

* $p < .05$ (paired samples t-test, 1-tailed)
De gelukkige bakker [1] fietst met opgeheven [2] hoofd door de straten, omdat zijn broodjes goed verkopen
The happy baker [1] cycles with raised [2] head through the streets, because his rolls well sell

General Discussion

In three experiments, Dutch complex sentences consisting of a matrix clause (SVO) followed by a second clause were presented auditorily. The Cross-Modal Lexical Priming (CMLP) paradigm was employed to examine the time course of verb priming (in comparison to noun priming) during the unfolding sentence. The results of Experiment 1 and 2 revealed priming of the verb directly at its offset, suggesting that aspects of the verb's interpretation are active immediately when the verb is encountered (with the caveat described in the discussion of Experiment 2). Stable and significant priming effects were found at temporally different positions during the remainder of the matrix clause and lasted until the end of the clause. The appearance of a conjunction, however, seemed to be a clear signal to stop this process. The results of a third experiment, examining the time course of priming of subject head nouns, suggested that the prolonged activation pattern found in the first two experiments is unique to verbs.

In the *Introduction* three hypothetically possible data patterns were put forward that sparked our interest in this work. The first possibility was a *de*activation–*re*activation pattern reflecting on-line gap-filling effects for the main verb, which in a Dutch declarative matrix clause has supposedly been moved from its base clause-final position to the second position in the clause (V2). This option can be discarded on the basis of the consistent priming effects observed at the intermediate test positions *before* the putative gap position at the end of the main clause in Experiments 1 and 2. Since verbs are not *de*activated at any point before the end of the clause, we cannot make any claims on *re*activation. These results are in clear contrast with the patterns that have been found in studies where the moved constituent was a noun. In such cases the meaning of the noun is activated when encountered, and then the activation disappears, only to reappear in and around the gap position. This pattern has been interpreted as a reflection of the recovery of canonical form in non-canonical structures. In the present set of experiments, the activation of the 'moved' verb was found to continue until the end of the clause in which it resides (and thus up until a putative canonical gap position for the verb). These data, taken at face value, suggest that verbs are *not re*activated at their base position, suggesting that the presumed existence of a 'copy' of the moved verb at a gap position may not drive the processing of verbs in V2 languages.

On the other hand, the data are also in clear contrast with a 'punctuate' verb priming pattern. This pattern, where priming was expected directly after the occurrence of the verb and not at any further positions, would have been a clear case demonstrating an absence of any measurable consequences of verb movement. However, the data show an intriguing pattern of prolonged verb priming, continuing past the typical time period observed for nouns (hypothetical data pattern 3). Moreover, the data suggest that the occurrence of a clausal boundary, and not simply expiry of a certain amount of time, signals the end point of verb activation. Whereas no effect was found at the test position after the conjunction in Experiment 1, a significant priming effect was found when the probe was presented with a similar delay (1500 ms after the verb), but at a different structural position, namely *before* the occurrence of the clause boundary in Experiment 2. This pattern contrasts with the data from Callahan et al. (submitted), where activation of the verb dissipated approximately 1200 ms downstream from the verb.

How does the finding of prolonged verb priming fit with previous findings on verb processing during sentence comprehension? When a verb is encountered in a sentence, its argument structure configurations are activated (again, MacDonald et al. 1994). One interpretation of such an effect is that the verb projects its possible arguments, setting up expectations or slots in which the arguments should appear (see also Shetreet et al. 2007, for a similar role for syntactic subcategorization frames). Besides these structural factors, there is some evidence that the parser also has immediate access to thematic properties (or rather, typical Agents and Patients, e.g., Ferretti et al. 2001). Given the relative immediacy of the availability of argument structure and thematic properties, why would a verb remain active until a clausal boundary? There are at least two possibilities. One is simply that the architecture of the sentence processing system requires data-driven operations that run their course without interference from other sources (cf. Frazier and Fodor 1978). Candidates for such data-driven operations are verb-argument structures, phrase structure strategies, and syntactic indices that allow immediate co-reference relations to be computed. For example, even in constructions where the argument structure is apparent before the verb is encountered, the argument structures nevertheless remain active at the verb as well (Shapiro et al. 1989). There is some evidence that similar routines underlie the activation of a verb's thematic properties (Ferretti et al. 2001; McRae et al. 1997, 2005); that is, thematic properties appear to be active before the verb is encountered (McRae et al. 2005) and also after (Ferretti et al. 2001). Thus, verbs may remain active because the architecture of the system requires them to be.

Yet a second, orthogonal account takes a more conceptual viewpoint, assuming that when listeners process a sentence their main goal is to understand the meaning of the individual words as well as the meaning of the whole message or proposition that the speaker wants to convey. Verbs play an interesting role in this process, as the meaning of the word itself and the meaning of the whole clause interact in subtle ways and may be difficult to tease apart. Verbs are highly polysemous (Fellbaum 1993; Gentner 1981) and depend on the sentence context for their exact meaning (Bencini and Goldberg 2000; Bonnotte 2008; Kersten 1998, 2003). Gentner and France (1988) found that if the meaning of a verb does not fit with a noun with which it co-occurs in a simple sentence context, participants are more eager to change the meaning of the verb than the meaning of the noun. Interestingly, these mutability effects are seen in on-line processing as well: an eye-tracking study by Pickering and Frisson (2001) showed that lexical ambiguity resolution for verbs is delayed compared to nouns. The suggestion of these authors is that the full interpretation of a verb is dependent on the NPs with which it combines in a particular sentence. Interestingly, this is also the case for non-ambiguous verbs that have multiple senses. To understand the full meaning of, for example, the verb *open*, one needs to know whether it concerns *opening a door*, or *opening a file*.

According to the *underspecification model* (Frisson and Pickering 1999) "the processor activates a single underspecified meaning for a verb with multiple senses and uses evidence from context to home in on the appropriate sense" (Pickering and Frisson 2001, p. 564). Since practically all verbs have multiple senses, delaying the interpretation process until the rest of the sentence is processed would make perfect sense. These studies suggest that verb interpretation constitutes the main part of sentence interpretation and is an ongoing process, which possibly only stops when a new clause and/or a new verb is encountered. During processing, each sentence constituent (the arguments, but possibly also other relevant information) is linked to the verb to zoom in on its specific interpretation and with that to the interpretation of the whole sentence (or clause).

In conclusion, the current data reveal new and important findings concerning the activation of verb meaning during on-line sentence interpretation. In clear contrast to patterns reported for nouns, verbs that occur early in a sentence were found to give rise to priming effects until the end of the clause. Potential mechanisms underlying this are form-driven processes for verb-argument structure or a 'semantically' oriented specification process for verb meaning in relation to the sentence or clause in which the verb occurs. Further studies need to address how these results generalize to other sentence structures and languages.

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