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# Visual priming and parsing preferences: A self-paced reading study of PP-attachment ambiguity in Dutch verb-final structures



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## Abstract

Understanding how language users navigate through syntactic ambiguities is crucial for unravelling the intricacies of sentence processing. This study explored ambiguity resolution within verb-final double prepositional phrase structures in Dutch. While previous research has largely focused on SVO structures such as those found in English, there is a scarcity of evidence regarding initial syntactic decisions in verb-final structures. The study pursued two aims: firstly, to investigate whether visual cues can direct the parser towards an intended interpretation; and secondly, to examine the potential of visual cues in priming verb subcategorization information within ambiguous sentences in the absence of linguistic input. A reading task was administered to address these objectives by assessing per-word reading times. Furthermore, ambiguity within the structures was resolved by presenting an animation clip that displayed the intended interpretation of each sentence before reading it. The results indicated that the animations provided before the reading task modulated the processing of NP- and VP-attachment interpretations of the ambiguous structures under study. However, these contextual cues did not prime subcategorized information of verbs earlier than their appearance within the sentence, as evidenced by unchanged reading profiles for the regions preceding the verb. This study demonstrates that visual contexts modulate the word-by-word processing of Dutch verb-final structures, and that verb argument structure appears to influence this process. The results are examined through various sentence processing theories, lending support to constraint-based models.

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**Keywords:** Double PP-attachment structures; Visual priming; Ambiguity resolution; Self-paced reading; Verb-final structures; Syntactic preference; Sentence processing

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## 1. INTRODUCTION

Sentence comprehension unfolds rapidly, compelling the human parser to form interpretations as linguistic elements are processed. Theories about the mechanisms driving sentence comprehension diverge, particularly in how they account for the activation of syntactic and contextual information. Traditional models, like the garden-path theory (Frazier, 1979, 1987), hold that the initial phases of sentence processing rely exclusively on syntactic structure. In contrast, interactive models argue that information from multiple sources, including lexical and contextual cues, work concurrently to shape comprehension (McRae et al., 1998; McRae and Matsuki, 2013; Trueswell et al., 1993, 1994). This parallel processing leads to multiple interpretations being considered and evaluated, with the most probable interpretation gaining prominence over time. These theoretical assumptions have been tested in studies examining structurally ambiguous sentences including reduced relatives (McRae et al., 1998), object/complement clauses (Sturt et al., 1999), and double prepositional phrases (Spivey et al., 2002). In these studies, it is generally observed that when there is ambiguity between two attachment sites, the parser has a preference for one attachment site over the other. It has been proposed that such preferences occur during parsing due to factors such as syntactic simplicity, plausibility, frequency, or contextual information (e.g., visual and referential context; Altmann and Steedman, 1988; Frazier and Rayner, 1982; Trueswell et al., 1993, 1994).

In addition to looking at ambiguous sentences, another approach towards identifying factors that may give rise to syntactic preferences is syntactic structural priming, which is proposed to take place when a prime stimulus structure facilitates the target structure (Bock, 1986). Cleland and Pickering (2003) showed that facilitation effects are stronger in production when the prime and target stimuli feature similar syntactic structures. Syntactic priming effects have been studied in production (e.g., Hartsuiker and Kolk, 1998; Bock and Griffin, 2000; Cleland and Pickering, 2003; Corley and Scheepers, 2002), and more recently, in comprehension (Arai et al., 2007; Ledoux et al., 2007; Thothathiri and Snedeker, 2008a, 2008b; Tooley et al., 2009; Traxler and Tooley, 2008). In comprehension, the priming effects appear to necessitate shared lexical elements, particularly the verb (see Tooley and Traxler, 2010; but see Traxler, 2008; Thothathiri and Snedeker, 2008a, 2008b).

Previous studies on syntactic priming have mostly used *linguistic* materials as a prime context in tasks adapted from Bock (1986), such as sentence completion and recall tasks (see, for example, Pickering and Branigan, 1998; Potter and Lombardi, 1998; Branigan et al., 2000a, 2000b; Thothathiri and Snedeker, 2008b). However, syntactic processing, particularly interpreting ambiguous structures, is affected by visual contextual information (e.g., Tanenhaus et al., 1995; Snedeker and Trueswell, 2004; Chambers et al., 2004; Altmann, 2004; Altmann and Kamide, 2009; Shoghi et al., 2022). Even when a visual context is briefly presented and then removed, merely recalling or envisioning that visual context has been argued to modulate eye movement patterns (see Huettig et al., 2011). Altmann and Kamide (2009) studied how predictive mechanisms operate during language comprehension. The authors revealed that the mental representations that are linked to synchronous linguistic and visual processing have a stronger association with their participants' eye movement patterns than when each type of linguistic and visual stimulus is processed separately. It is conceivable that visual context can shape mental images of the events that are described in a statement. The present study aims to take a step towards addressing the question of how extensively these abstract representations are linguistically encoded.

We draw upon different models of sentence processing and syntactic priming to investigate the initial syntactic analysis of globally ambiguous structures and explain the probable syntactic preferences. Firstly, we examine whether presenting a visual context as a means of disambiguation can guide the initial syntactic analysis of globally ambiguous verb-final structures. Additionally, we examine whether syntactic information can be primed in a reading comprehension task by a prior visual context that contains no explicit linguistic input. Dutch provides a suitable testing ground to meet this aim, due to its variable verb position in the surface structure of matrix and complement clauses. Following a Subject-Verb order, Dutch matrix clauses are verb-second, whereas complement structures have a verb-final order (see 1–2).

(1) Verb second structure (adapted from Shoghi et al., 2022: 6)

De	vrouw	zet	de	klok	naast	de	foto	op de	tafel
The.FEM	woman	place.PRES	the.FEM	clock	next to	the.FEM	photo	on the.FEM	table

*The woman puts the clock next to the photo on the table.*

## (2) Verb final embedded clause (adapted from Shoghi et al., 2022: 6)

De vrouw die de klok naast de foto op de tafel zet  
 The<sub>.FEM</sub> woman who<sub>.FEM</sub> the<sub>.FEM</sub> clock next to the<sub>.FEM</sub> photo on the<sub>.FEM</sub> table place<sub>.PRES</sub>  
*The woman who puts the clock next to the photo on the table.*

Choosing a verb-final structure allows the parser to integrate all lexical information before the verb, unlike simple clauses where key prepositional phrases follow the verb. By using verb-final structures, this study complements the work reported in Shoghi et al. (2022), who used verb-second structures in Dutch to explore the impact of lexical information on processing. Shoghi et al. (2022) found that prior visual context, such as animation clips, could guide initial parsing decisions based on the verb's argument structure in a reading task. Specifically, in sentences with two-argument verbs (e.g., “open”), the context facilitated the reading of the less preferred interpretation (i.e., NP-attachment), whereas this was not observed with sentences containing three-argument verbs (e.g., “put”).

In the current study, we employ the same paradigm and materials but shift the focus to verb-final structures. This is particularly useful for several reasons. Firstly, Dutch verb-final structures provide a unique syntactic environment where all lexical information preceding the verb can be integrated before reaching the verb, contrasting with non-complemented simple clauses where critical prepositional phrases follow the verb. This allows us to investigate whether the effects observed by Shoghi et al. (2022) in verb-second structures can be generalized to verb-final structures. By comparing these different linguistic contexts, we can better understand the extent to which visual context aids in ambiguity resolution across diverse syntactic configurations.

Moreover, by using the same paradigm and materials, we ensure that any observed differences or similarities in parsing strategies can be attributed to the structural differences between verb-second and verb-final sentences rather than differences in experimental design or materials. This methodological consistency strengthens the reliability and comparability of our findings. Such an approach is supported by research that emphasizes the benefits of methodological consistency in comparative studies, as it reduces confounding variables and enhances the internal validity of the research (Trochim, 2006; Shadish, et al., 2002).

We hypothesize that the visual context will similarly aid in resolving syntactic ambiguities in Dutch verb-final structures, as observed in the verb-second language study by Shoghi et al. (2022), and that it will reduce per-word reading times by guiding participants towards intended interpretations. However, due to the inherent syntactic differences, the specific attachment preferences (NP vs. VP) and the influence of verb argument structure may differ. Verb-final structures force readers to hold multiple syntactic possibilities in memory until the verb's argument structure can be integrated. This delay in encountering the verb can lead to more pronounced syntactic ambiguities, as readers may not have sufficient information to resolve the structure until later in the sentence. Consequently, when the verb is finally encountered, readers often need to reanalyze and adjust their initial interpretations. This reanalysis is more cognitively demanding and results in significant reading time disruptions, especially in regions where less preferred interpretations occur. Therefore, we anticipate a stronger influence of verb argument structure on processing times, given the delayed position of the verb in the sentence.

### 1.1. Lexical information and prepositional phrase attachment preferences in verb-second vs verb-final constructions

Models of sentence processing vary in the prominence they assign to the contribution of lexical information to initial parsing decisions. Constraint-based theories (e.g., MacDonald, 1994; Taraban and McClelland, 1988; Trueswell et al., 1993) suggest that lexical and syntactic information are activated simultaneously, supporting the idea that lexical information contributes early in the parsing process. In contrast, the garden-path theory (Frazier, 1979, 1987) argues for an autonomous role of syntax, relying on principles like minimal attachment<sup>1</sup> and late closure,<sup>2</sup> where syntactic structures are formed independently without awaiting lexical head identification. Yet, diverging from the standpoint of the garden-path theory, there is evidence acknowledging the vital role of lexical information, such as the verb's argument structure, while making attachment decisions (e.g., Britt, 1994; Garnsey et al., 1997; MacDonald, 1994; Trueswell et al., 1993; Staub, 2007). Words in a sentence tend to join the nearest word that can be their head as the sentence progresses.

<sup>1</sup> Under minimal attachment, the simplest possible syntactic structure is constructed by opting for the configuration with the fewest upper-level nodes in the syntactic tree.

<sup>2</sup> The late closure principle suggests that, when grammatically possible, newly introduced elements should attach to the most recent clause or phrase being processed.

Prepositional phrase (PP) attachment ambiguity has been widely explored in sentence processing research. In structures where a PP either attaches to the verb or the noun (V-NP-PP), such as in [Tanenhaus et al.'s \(1995: 1633\)](#) example “put the apple on the towel in the box. . .”, the parser faces two potential interpretations. The PP ‘on the towel’ may attach to the verb, indicating a location for the action, or it may modify the noun, specifying its position. Research indicates a general preference for verb-phrase attachment in these cases, with various theories attributing this preference to factors like syntactic simplicity and contextual plausibility. That is, based on the minimal attachment principle, the parser often favors constructing structures that are syntactically simple. Therefore, in a V-NP-PP order, high/VP attachment generates a less complex syntactic structure than low/NP attachment and is the preferred attachment in both verb-second and verb-final sentences. Conversely, late closure posits that new elements are to be integrated into the processed clause, provided it is grammatically permissible. This principle is only employed when the application of minimal attachment does not result in a preferred structure. Thus, if the structures do not differ in syntactic complexity, late closure would predict attachment to the NP in both verb-second and verb-final sentences.

Interactive frameworks propose that preferences for certain syntactic attachments, such as VP-attachment, can be influenced by contextual factors. For example, the referential theory ([Altmann and Steedman, 1988](#)) suggests that when a sentence involves ambiguity between a noun modifier and verb-phrase attachment, the parser tends to favor interpretations that minimize unnecessary assumptions. Specifically, when a definite noun phrase is introduced in a context where no prior references exist, listeners are more likely to interpret it as referring to a single entity, leading to a preference for verb-phrase attachment. Furthermore, this model predicts that in both verb-second and verb-final sentences, when there is no surrounding context, VP-attachment is preferred over NP-attachment.

There has been extensive research on PP-attachment ambiguity in languages that have a SVO word order, mainly in English (e.g., [Britt, 1994](#), [Britt et al., 1992](#); [Chambers et al., 2004](#); [Clifton and Ferreira, 1989](#); [Ferreira and Clifton, 1986](#); [Rayner et al., 1992](#); [Snedeker and Trueswell, 2004](#); [Tanenhaus et al., 1995](#)), whereas evidence from verb-final structures is scarce. In a study on PP attachment preferences in Dutch verb-final structures, [Frazier \(1987\)](#) found a VP-attachment preference for the prepositional phrase, similar to English, and in line with the minimal attachment principle. In a recent study, [Coopmans and Schoenmakers \(2020\)](#) employed a self-paced reading task to examine the PP attachment in locally ambiguous structures in Dutch by manipulating the argument/adjunct function of PPs and their position (e.g., *De aannemer heeft op het dakterras bespaard/gewerkt* ‘The contractor has on the roof terrace saved/worked’, see [Coopmans and Schoenmakers, 2020: 42](#)). The authors reported no argument attachment preference for the postverbal PPs and an adjunct attachment preference for the preverbal PPs. This finding does not support the currently held view, mostly based on the data from English, favouring argument attachment, and hence emphasizes the necessity of crosslinguistic research in this domain.

In a previous study on the processing of ambiguous verb-second structures in Dutch, [Shoghi et al. \(2022\)](#) found that prior visual context, provided through animation clips, could influence initial parsing decisions based on the verb’s argument structure. Specifically, for sentences with two-argument verbs (e.g., “open”), the context aided in reading the less preferred interpretation (i.e., NP-attachment). However, this effect was not observed in sentences with three-argument verbs (e.g., “put”). The effectiveness of such visual context in guiding parsing decisions supports the notion that visual information can help form a mental representation that can be linguistically mapped. In the current study, we employed the same animated clips to illustrate the possible interpretations of the verb-final ambiguous structures under investigation, as shown in (3).

(3) Examples adapted from [Shoghi et al. \(2022\)](#)

a. NP-attachment

De	jongen	die	NP[NP[de	jas]	PP <sub>1</sub> [Op	de	stoel]]	PP <sub>2</sub> [naast	de	deur]	hangt,...
The	boy	who	NP[NP[the	coat	PP <sub>1</sub> [On	the	chair]]	PP <sub>2</sub> [next to	the	door]	hangs,...

‘The boy who hangs the coat that is on the chair next to the door, ...’

b. VP-attachment

De	jongen	die	NP[de	jas]	PP[PP <sub>1</sub> [op	de	stoel]]	PP <sub>2</sub> [naast	de	deur]]	hangt,...
The	boy	who	NP[the	coat	PP[PP <sub>1</sub> [on	the	chair]]	PP <sub>2</sub> [next to	the	door]]	hangs,...

‘The boy who hangs the coat on the chair that is next to the door, ...’

In (3), the sentence ‘The boy who hangs the coat *on the chair next to the door, ...*’ has two interpretations. For the first interpretation (3a), there would be a clip of a boy hanging one of the two coats (the one on the chair, not the one on the table) next to the door. For the second interpretation (3b), the boy will have a single coat, which he will hang on the chair next to the door, not on the other chair (see [section 2.2](#)). We investigated whether a preceding visual context, presented

as animated visual clips, enhances the reading of an upcoming sentence by mitigating the garden-path effect in verb-final structures.

### 1.2. Syntactic priming

Several ambiguous PP-attachment studies utilised syntactic priming designs, which often start with the presentation of a prime including a syntactic form, followed by a target sentence with a similar structure. Branigan et al. (2005), in a comprehension study, used globally ambiguous prime and target sentences including *with-PPs* each paired with pictures that resolved the ambiguity. They found that syntactic priming affected the decision of participants regarding the interpretation they acquired. Boudewyn et al. (2014) investigated the effect of reading a prime expression on the processing of a target structure including PP attachment ambiguity (e.g., [. . .] *blanket on the floor on the bed.*). They found that processing an NP-attached structure reduces the reading times for the following syntactically similar structure, which is taken to be a sign of facilitation effect. In sentence contexts, such as those studied by Boudewyn et al. (2014), greater reading disruptions occur when readers arrive at the final prepositional phrase (i.e., 'on the bed'), due possibly to a misinterpretation of the first prepositional phrase as indicating a goal or location. It is plausible to reason that such interpretation failures, as measured by reading disruptions on the final prepositional phrase, might be reduced by synchronously presenting visual context to facilitate the modifier interpretation of the first prepositional phrase (see, e.g., Tanenhaus et al., 1995) or by structurally priming readers with another sentence of a similar syntactic structure (Traxler, 2008).

Syntactic priming effects have been accounted for by several underpinning mechanisms ranging from residual activations to implicit learning and memory (see Pickering and Branigan, 1998; Bock and Griffin 2000; Chang et al., 2000; Reitter et al., 2011). Detailing all accounts is outside the scope of this study, but we do address the residual activation mechanism because of our interest in the abstract representation of meaning at word level. According to Pickering and Branigan (1998), short-term residual activation resulting from the processing of words and their relevant structural representations enhances the possibility of their reuse in a subsequent language production task. Based on the residual activation account, a lemma node and the combinatorial nodes that represent the subcategorization information of that lemma node are selected at the same time. When an activated combinatorial node does not decay immediately, syntactic priming occurs. For instance, upon the selection of the lemma node for the verb *to give*, two combinatorial nodes are selected (either NP-NP, or NP-PP) and one of them will be licensed depending on the construction being processed.

So far, investigations into the residual activation account have solely utilized verbal primes representing a syntactic structure. Conversely, in this study, we presented animation clips, each featuring a character performing an action, aiming to ascertain whether observing these actions could trigger activation of the lemma node and subsequently prime subcategorization information of the verb.

### 1.3. The current study

We investigate ambiguity resolution in prepositional phrase attachments using verb-final structures in Dutch. There is evidence that in verb-second structures (e.g., SVO), the lexical properties of the verb (i.e., the subcategorization information) creates expectations regarding the syntactic roles assigned to the upcoming words in a sentence (e.g., Britt, 1994, Shoghi et al., 2022). However, since most research in this area is done on languages with an SVO word order, in particular, on English, there is scarcity of evidence concerning the initial syntactic decisions when the verb is unknown until the end of the sentence (i.e., in verb-final structures). Also importantly, it is expected that contextual information accompanying a verb-final structure provides useful hints for the parser that guides initial syntactic decisions. However, in an experimental setting, delivering contextual information in a way that is analogous to a real-life situation is not straightforward. To account for this problem, we designed a self-paced reading experiment with visual priming contexts using animation clips that clearly presented the meaning conveyed by each sentence (see above).

This investigation aims to understand whether prior visual context guides the interpretation of globally ambiguous verb-final structures toward a desired interpretation during the initial stages of analysis and whether it primes the verb's subcategorization information. In the absence of contextual cues, verb-final structures may lead to similar processing of two and three argument verbs. However, if context primes the verb's subcategorization information, behavior akin to verb-second and SVO structures may emerge. Garden-path structures usually lead to longer reading times in disambiguating regions, when reader interpretation clashes with context. In double PP attachment ambiguities, we expect the critical region to be the second prepositional phrase where readers realize the syntactic structure that they have assigned to the first PP (i.e., verb modifier) leads to an unintended interpretation. Therefore, if contextual cues can avoid the garden-path effect, comparing the reading times in NP- and VP-attachment conditions will return no significant difference between these conditions in PP2. However, if context cannot override the preference for one attachment type,



we expect to observe longer reading times at the critical regions for the non-preferred interpretation that is NP-attachment based on minimal attachment principle and referential hypothesis.

## 2. METHODS

### 2.1. Participants

A total of 67 native speakers of Dutch (20 male, 47 female, age range = 18–30, mean age = 23.68 years, SD = 2.92) were included in the analysis after participant exclusion (n = 5). The participants confirmed that they spoke Dutch natively from birth, and that they were between 18 and 30 years old and had no history of language or hearing impairments. All participants provided informed consent digitally and were remunerated with €8 for their participation. This study and experimental procedures reported here have received the approval of the University of Groningen Ethics Committee (CETO approval number 75932560).

### 2.2. Design and materials

Experimental materials were adapted from Shoghi et al. (2022), consisting of 80 experimental sentences with subject relative clauses in four conditions. While Shoghi et al. (2022) focused on verb-second (SVO) structures, we adapted these sentences to verb-final (SOV) constructions for this study, restructuring items such as (4a) from main clauses to subordinate clauses like (4b).

(4) Example materials adapted from Shoghi et al. (2022):

- a. Hij **hangt** de jas op de stoel naast de deur en gaat ernaast staan.  
He **hang**.PRES the.FEM coat on the chair next to the.FEM door and stand.PRES next to it.  
'He hangs the coat on the chair next to the door and stands next to it.'
- b. De jongen die de jas op de stoel naast de deur hangt, gebruikt een kledinghanger.  
The boy who the coat on the.FEM chair next to the.FEM door **hang**.PRES, use.PRES a clothes hanger'  
'The boy who hangs the coat on the chair next to the door, uses a clothes hanger.'

The 80 experimental items comprised two groups of 40 items depending on the verb argument structure; that is, verbs with two arguments (e.g., open, read, cut) and three arguments (e.g., put, throw, hide). Regarding two-argument verbs, in an NP-V-NP sequence, one NP functions as the subject and another NP functions as the direct object. However, the three-argument verbs require an additional component in the form of a PP representing a location in an NP-V-NP-PP sequence. There were two categories of three-argument verbs based on whether the PP was obligatory (n = 27) or optional (n = 13). Ambiguity in these structures arose either from VP-attachment (where the PP attaches to the verb) or from NP-attachment (where the PP attaches to the preceding noun). Argument structure and attachment type served as experimental factors. Thus, we formulated four conditions in a 2 × 2 design, as summarized in Table 1. Additionally, 80 filler items in the form of subject relative clauses were included (e.g., De chef ziet de vrouw die de rekening wil en roept de ober: 'The chef sees the woman who wants the menu and calls the waiter.').

Table 1

Examples of experimental items per condition used in the current experiment ( adapted from Shoghi et al., 2022).

Condition 1: VP-Attachment/3-Argument Verbs (VPA/3AV)	De jongen die NP[de jas] PP[PP1[Op de stoel] PP2[naast de deur]] hangt, ... The boy who NP[the coat] PP[PP1[on the chair] PP2[next to the door]] hangs, ... The boy who hangs the coat on the chair that is next to the door, ...
Condition 2: NP-Attachment/3-Argument Verbs (NPA/3AV)	De jongen die NP[NP[de jas] PP1[Op de stoel]] PP2[naast de deur] hangt, ... The boy who NP[NP[the coat] PP1[on the chair]] PP2[next to the door] hangs, ... The boy who hangs the coat that is on the chair next to the door, ...
Condition 3: VP-Attachment/2-Argument Verbs (VPA/2AV)	De man die NP[de gitaar] PP[PP1[Op de stoel] PP2[naast de deur]] bespeelt, ... The man who NP[the guitar] PP[PP1[on the chair] PP2[next to the door]] plays, ... The man who plays the guitar on the chair that is next to the door, ...
Condition 4: NP-Attachment/2-Argument Verbs (NPA/2AV)	De man die NP[NP[de gitaar] PP1[Op de stoel]] PP2[naast de deur] bespeelt, ... The man who NP[NP[the guitar] PP1[on the chair]] PP2[next to the door] plays, ... The man who plays the guitar that is on the chair next to the door, ...

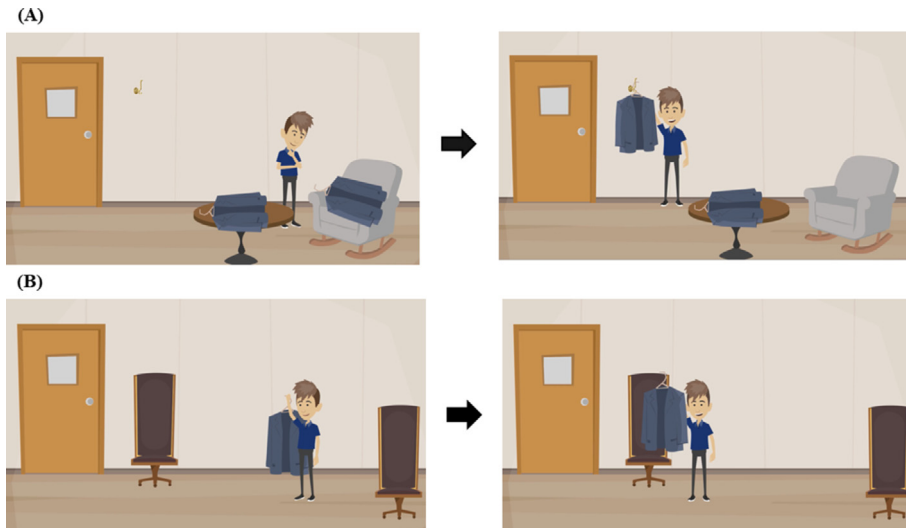


Fig. 1. Stills from the Animated Clips Demonstrating NP-Attachment (A) and VP-Attachment (B) Interpretations for the Sentence 'The boy who hangs the coat on the chair next to the door, uses a clothes hanger'.

Similar to Shoghi et al. (2022), we utilized short visually animated clips to direct readers toward an intended NP- or VP-attachment interpretation. A total of 160 animated clips were generated as experimental items, along with 80 animations as filler items. All were created using the Vyond platform.<sup>3</sup> The animation clips contained no sound and lasted six to nine seconds. The clips depicted the sentence materials in either of the intended interpretations of a given ambiguous sentence using the same background settings, characters, and the direction of movement (see Fig. 1).

The composition of those animated clips was similar to Shoghi et al. (2022), as illustrated in Fig. 1, each visual material featured a human referent with two identical objects, such as two chairs or two coats, situated in distinct locations. Fig. 1A illustrates a visual depiction of an NP-attachment interpretation, in which one of the two coats is resting on the chair and the other is elsewhere. The human subject character, the boy, hangs the coat that is on the chair next to the door. Fig. 1B, by contrast, demonstrates a visual depiction of a VP-attachment interpretation of our linguistic stimulus, in which a single coat and two chairs appear. The boy hangs the coat on the chair that is next to the door. In each clip, the inclusion of two referents for an object was intended to account for Crain and Steedman's (1985) 'referential theory', which posits that when there is only one referent for an object in the context, there is a strong inclination toward VP-attachment. By introducing two referents, we aimed to mitigate such a bias and provoke a preference for the intended interpretation. As outlined in Table 2, the critical regions for analysis encompassed the second prepositional phrase, the preceding noun, and the spillover regions. The experimental sentences were 15 words long and had similar structures.

### 2.3. Procedure

We programmed the stimuli using the Gorilla.sc online platform (Anwyl-Irvine et al., 2020). We used a non-cumulative self-paced reading task (Just et al., 1982), in which sentences were presented in the middle of the screen as truncated dashed lines. The participants pressed the spacebar to read each word in sequence at their own pace. When the spacebar was pressed, the dashes representing a single word were replaced with the word, and pressing it again reverted the dashes to continue to the next word. The rest of the procedure was identical to Shoghi et al. (2022), we measured non-cumulative reading times spent on each segment.

There were 8 practice trials prior to the experiment. The experiment consisted of 160 experimental trials presented in a fixed, pseudorandomised order, split into four 40-trial blocks. An equal number of trials from each condition were present in each block in a cross-balanced manner. The same sentence material appeared only once in a condition manipulation. After completing each block, participants could take an unlimited break. To ensure attentiveness, participants answered comprehension questions presented pseudo-randomly after one fourth of the trials (i.e., 40 questions in total). These questions addressed visual characteristics of the animation clips (e.g., Was the color of the woman's hair

<sup>3</sup> <https://www.vyond.com/>.



Table 2  
Segmented critical across the sentence stimulus.

Reg.	Pre-critical region						R-1	R-2	R-3	R-4	R-5	R-6
							PP2 prep	PP2 article	PP2 noun	Verb	Spillover1	Spillover 2
Dutch	...die	de	jas	op	de	stoel	naast	de	deur	hangt	gebruikt	een...
Eng.	...who	the	coat	on	the	chair	next to	the	door	hangs	uses	a...

brown?) or specific details from the sentences (e.g., Does the flight come from France?). Explicit questions about attachment preferences were avoided. The participants were instructed to answer 'yes' by pressing 'p' or 'no' by pressing 'q' on their keyboard. They were provided with feedback which appeared for 500 ms in green or red color script on a black background in relation to their 'correct' or 'incorrect' responses, respectively. The experiment lasted approximately one hour, and the participants used their own computers.

#### 2.4. Data analysis

Initially, we examined the performance of the participants on the comprehension questions so that we could identify and exclude any inattentive participants. Following [Witzel et al. \(2012\)](#), we set a threshold of 80% accuracy rate which led to the exclusion of five out of 72 participants. Reading times below 100 ms and above 4000 ms were removed equating to 1.7% of the data. Statistical analyses on the reading times (RTs) data were computed in R ([R Core Team, 2021](#)) using the linear mixed-effects regression models with the *lmer* function from the 'lme4' package (version 1.1-27.1; [Bates et al., 2015](#)). The models incorporated Attachment Type (NP vs. VP) and Verb Argument Structure (2 vs. 3) as fixed effects, and experimental participants and trials as random intercepts and slopes as appropriate (see [Baayen, 2008](#)). We also included word length in the models to control for differences in region lengths. The rest of the data analysis protocol regarding sum-to-zero coding, model comparisons, multicollinearity checks, and log-transformation of RTs were identical to that reported in [Shoghi et al. \(2022\)](#).

### 3. RESULTS

[Table 3](#) displays the mean RTs for each region of interest under different conditions; [Fig. 2](#) illustrates the mean RTs across the four conditions.

Statistical outputs (see [Table 4](#)) did not show any effects of Attachment Type or Argument Structure in R.1 (i.e., the preposition in PP2). The interaction between Attachment Type and Argument Structure was not significant in this region either. In R.2, the participants read the NP-attachment condition at a slower pace than the VP-attachment condition. However, there was no effect of argument structure, nor an interaction between these variables. In the following region (i.e., R3: the noun in PP2), we observed neither a significant effect of attachment type nor of Argument Structure. A marginally significant interaction between Attachment Type and Argument Structure was found, however, the post-hoc comparisons yielded no differences between VP and NP-attachment, neither in 2- nor in 3-argument structures ([Table 5](#)).

In R4 (i.e., the verb), we found longer reading times for the NP-Attachment condition, but no effect of Argument Structure. The interaction between the two variables was significant. As presented in [Fig. 3](#), further investigations using Mul-

Table 3  
The mean RTs in milliseconds for each region across for Two- and Three-argument verb conditions (SD = Standard deviation around the mean).

Region	VPA/3AV		NPA/3AV		VPA/2AV		NPA/2AV	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
R1	265.26	120.11	272.35	136.81	274.57	124.88	278.17	162.99
R2	264	105.95	272.92	128.82	278.55	122.85	281.89	141.08
R3	275.54	120.67	277.77	120.64	291.59	130.58	286.70	129.03
R4	300.68	158.28	321.67	184.28	328.77	207.57	335.31	235.97
R5	316.8	162.89	325.26	163.01	338.49	179.25	344.60	167.84
R6	324.72	148.03	335.87	179.81	326.54	126.59	335.05	149.38

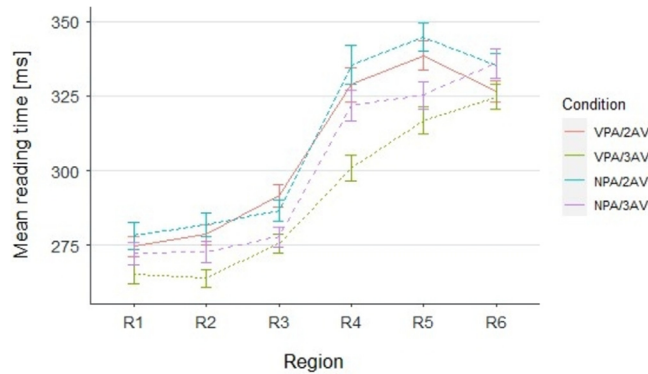


Fig. 2. Visual illustration of RTs across regions of interest.

multiple Tukey contrasts revealed a significant difference in one contrast, namely VP-Attachment/3-Argument compared to NP-Attachment/3-Argument conditions (Table 5). Similarly, in the spillover regions, including R5 and R6, we observed longer reading times for the NP-Attachment condition. The effect of Argument Structure was marginally significant in R5 but not significant in R6. The interaction between Argument Structure and Attachment Type was not significant in either R5 or R6. We observed a significant effect of Word Length in R1, but not in other regions.

#### 4. DISCUSSION

In this study, we used a visually-enhanced self-paced reading experiment. That is, visual contextual stimulus was presented in a form of animated short clips before each sentence in the reading task. The reading task included sentences with ambiguous verb-final structures in Dutch. This experimental setting allowed us to examine (i) whether a prior visual context can guide the reading of verb-final globally ambiguous structures toward one interpretation during the initial stages of processing, and if so, whether the argument structure of the verb plays a role in this process, (ii) whether this type of context can prime the subcategorization information of the verb in verb-final structures. The results showed that watching a disambiguating animation clip before reading an ambiguous sentence differed in its effects depending on whether it biased towards an NP or VP interpretation. That is, when the clips displayed an NP-attachment interpretation, processing of the critical regions was slowed down compared to the reading of sentences that were followed by a clip representing a VP-attachment interpretation.

This finding entails that contextual cues can influence the early stages of sentence analysis, thereby shaping subsequent interpretation, but the extent they can facilitate processing is a matter of competition between different sources of information. In other words, in a competition between contextual and syntactic information, there are two possible outcomes. A possibility is that the context facilitates parsing when it aligns with the syntactic bias of the structure (i.e., VP-attachment). Alternatively, the VP-attachment animation clips have no facilitative effect per se, while the NP-attachment clips introduce interference, thus leading to slowing down in reading times. In syntactic priming literature, priming effects are generally stronger for non-preferred structures (Ferreira and Clifton, 1986; Trueswell, et al., 1994). Our results suggest that while the preferred VP-attachment structure might benefit from contextual alignment, the observed effect might also be due to the NP-attachment context disrupting the preferred parsing strategy. This aligns with findings that non-preferred structures typically elicit longer reading times due to the additional cognitive load required for resolution (Mitchell et al., 1995).

Furthermore, our findings indicated that the animation clips did not influence the processing of the second prepositional phrase based on the verb's argument structure. Sentences with two- and three-argument verbs were processed similarly up to the verb region, where we observed an interaction between attachment type and argument structure. This interaction revealed that processing was facilitated for three-argument structures when the animated clips guided the reader towards a VP-attachment interpretation, but this was not the case for two-argument structures. Traces of this effect were observable in the region following the verb (i.e., the first word in the spillover region), where reading time was marginally increased for three-argument structures with clips representing the VP-attachment. These findings suggest that the contextual cues used in this study could not prime the subcategorization information of the verb. However, once the verb was identified by the reader, processing of NP-attachment/three-argument structures took longer compared to all other conditions.

Table 4

Output of the Global Mixed-effects Log-transformed RT Model (outliers excluded) for the Critical and Spillover Regions.

Fixed effects	Estimate	SE	df	t	p
<i>Region 1: De jongen die de jas op de stoel <b>naast</b> de deur hangt, gebruikt een kledinghanger.</i>					
(Intercept)	5.510	0.039	80.127	142.499	<2e-16***
Attachment (NP)	0.009	0.007	5035.244	1.283	0.200
Argument (3)	-0.036	0.024	77.058	-1.460	0.148
Word length	-0.031	0.009	87.233	-3.645	0.000 ***
Att:Arg	0.018	0.014	5038.678	1.261	0.207
<i>Region 2: De jongen die de jas op de stoel naast <b>de</b> deur hangt, gebruikt een kledinghanger.</i>					
(Intercept)	5.516	0.062	124.672	88.456	<2e-16***
Attachment (NP)	0.016	0.007	5105.397	2.301	0.021 *
Argument (3)	-0.038	0.025	77.024	-1.538	0.128
Word length	-0.015	0.027	77.620	-0.566	0.573
Att:Arg	0.017	0.014	5105.531	1.213	0.225
<i>Region 3: De jongen die de jas op de stoel naast de <b>deur</b> hangt, gebruikt een kledinghanger.</i>					
(Intercept)	5.568	0.037	89.031	148.504	<2e-16***
Attachment (NP)	-0.007	0.007	5035.573	-0.957	0.338
Argument (3)	-0.039	0.027	77.007	-1.463	0.148
Word length	0.003	0.009	78.656	0.370	0.713
Att:Arg	0.026	0.014	5090.584	1.865	0.062
<i>Region 4: De jongen die de jas op de stoel naast de deur <b>hangt</b>, gebruikt een kledinghanger.</i>					
(Intercept)	5.645	0.043	90.605	131.445	<2e-16***
Attachment (NP)	0.030	0.008	4779.035	3.607	0.000 ***
Argument (3)	-0.014	0.033	77.023	-0.422	0.674
Word length	0.014	0.007	83.616	1.910	0.059.
Att:Arg	0.047	0.016	5067.932	2.924	0.003 **
<i>Region 5: De jongen die de jas op de stoel naast de deur hangt, <b>gebruikt</b> een kledinghanger.</i>					
(Intercept)	5.728	0.039	91.365	148.337	<2e-16***
Attachment (NP)	0.019	0.008	5116.095	2.343	0.019 *
Argument (3)	-0.054	0.029	77.004	-1.862	0.066
Word length	-0.012	0.008	78.710	-1.560	0.123
Att:Arg	0.006	0.016	5115.991	0.389	0.697
<i>Region 6: De jongen die de jas op de stoel naast de deur hangt, gebruikt <b>een</b> kledinghanger.</i>					
(Intercept)	5.729	0.037	86.442	154.362	<2e-16***
Attachment (NP)	0.019	0.007	5067.584	2.722	0.006 **
Argument (3)	-0.012	0.029	77.003	-0.410	0.683
Word length	0.002	0.008	79.846	0.228	0.821
Att:Arg	0.011	0.014	5051.534	0.792	0.429

**Note.** RTs were natural log transformed. Word length was mean-centered. Attachment Type and Argument Structure are abbreviated as Att and Arg in the rows representing an interaction.

In the present study, we used verb-final structures where the lexical head (i.e., the verb) appeared at the end of the sentence. Given the location of the lexical head, the readers had to parse the earlier elements of the sentence with no knowledge of the verb's argument structure. In locative PP-attachment ambiguities, the existence of a default syntactic bias for the PP to attach to the VP has been validated by different models of sentence processing. In syntax-first account this bias is explained by the Minimal Attachment principle. The autonomy of syntax, which is the underlying building block of this principle, implies that regardless of the position of the lexical head, when VP-attachment leads to the formulation of a simpler structure, it is considered the preferred parse. Furthermore, the referential theory also assumes a general preference for VP-attachment in the absence of contextual cues because normally the parser assumes only one referent for the NP and therefore modifying it with a prepositional phrase would yield redundant information.

While evidence on verb-final structures is scant, our findings support [Frazier's \(1987\)](#) study on Dutch verb-final structures which indicates a preference for VP-attachment. Additionally, by corroborating the predictions of both the minimal attachment principle and the referential theory, the varying reading times for NP- and VP-attachment of PP2 in the

Table 5  
Pairwise Comparison of Argument Structure and Attachment Type for Region 3 (Noun in PP2) and Region 4 (Verb).

Region	Contrast	Estimate	SE	df	<i>t</i>	<i>p</i>
R3	VPA/2AV- NPA/2AV	0.020	0.01	5094.4	1.997	0.189
Noun in PP2	VPA/3AV- NPA/3AV	-0.006	0.01	5099.4	-0.643	0.918
R4	VPA/2AV- NPA/2AV	-0.006	0.012	4950	-0.510	0.957
Verb	VPA/3AV- NPA/3AV	-0.053	0.012	5109.6	-4.627	0<.0001

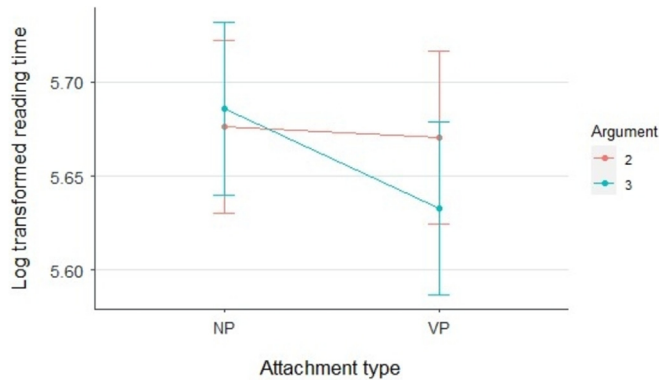


Fig. 3. Interaction Effect between Attachment Type and Argument Structure in Verb Region Based on the Model Output.

examined structures could indicate a potential preference for VP-attachment. This apparent preference for VP-attachment, or alternatively, the aversion to NP-attachment, seems to be so pronounced that even contextual cues are insufficient to mitigate the processing costs associated with the non-preferred NP-attachment reading. Indeed, the visual contextual cues proved to be used both in parallel with syntactic information and in competition with it. They were processed in parallel because we observed different processing behavior for the sentences representing VP- and NP-attachment depending on the clips preceding them. They were in competition because processing of the non-preferred NP-attachment structures was slowed down compared to the VP-attachment structures from PP2 onward, meaning that syntactic information (i.e., attachment type) could override contextual information. The competition observed between the syntactic and contextual sources of information provides support for the constraint-based accounts (McRae et al., 1998; McRae and Matsuki, 2013; Trueswell et al., 1993, 1994) and undermines the syntax-first approach which argues that in the early stages of sentence analysis, the parser depends only on syntactic information (see e.g., Frazier and Rayner, 1982; Tanenhaus et al., 1995). If this was the case, we would not have observed a difference between the processing of VP- and NP-attachment interpretations which became known to the readers only through the contextual cues.

Shoghi et al. (2022) observed that in an ambiguous verb-second double PP structure (e.g., *He hangs the coat on the chair next to the door.*), visual contextual cues lead to a similar processing of VP- and NP-attachment interpretations in 2-Argument but not in 3-Argument structures where sentences preceded by NP-attachment biased clips were read slower than those preceded by VP-attachment biased clips. In the present study, however, we did not observe an interaction between the argument structure and attachment type until the reader reached the verb. At this point, we observed similar reading behaviour for 2-Argument NP- and VP-attachment conditions. However, in case of the 3-Argument structures, reading the NP-attachment condition took significantly longer than the VP-attachment condition. In such verb-final structures, when the readers reach the verb, they realize that the sentence is grammatically complete, and they already engage in wrapping up the message. Taking this into account, we speculate that the visual cues facilitated the holistic comprehension of the text when there was no strong syntactic preference for an attachment type. That is, reading of all conditions were facilitated except for the NP-attachment/3-Argument condition where the syntactic bias imposed by the verb's argument structure was hard to overcome. It can also be claimed that the clips hindered the NP-attachment/3-Argument condition, where the syntactic bias imposed by the verb's argument structure was difficult to overcome.

It is conceivable that visual priming was a strong influence on our data. We employed visual contexts displaying the content of sentence stimuli. While evidence for structural priming exists (e.g., Pickering and Branigan, 1998; Thothathiri and Snedeker, 2008a, 2008b; Branigan et al., 2000a, 2000b), we considered whether visual information in our design could result in visual/non-linguistic priming effects. We were mainly interested in examining whether knowledge of the

verb in an upcoming sentence (gained by watching a character performing an action) could prime the subcategorization of that verb while reading a target verb-final sentence. Although our design did not allow for directly measuring the magnitude of priming effects, based on the findings of Shoghi et al. (2022) who did a similar research but on verb-second structures, we expected that if the contextual cues were able to prime the subcategorization information of the verb, we would observe an effect of argument structure on the reading times of the regions preceding the verb, more specifically, in PP2; however, the results showed no evidence for such an effect. This finding implies that in verb-final structures, merely presenting a visual depiction of sentence meaning with no explicit linguistic input cannot readily influence the readers' parsing decisions based on the argument structure of the verb before encountering it. Additionally, it appears that the animation clips might influence the parser's tendency towards a specific attachment type even before the verb is encountered. This interpretation is supported by the reading time data observed in Region 2 (R2), which corresponds to the article in the prepositional phrase (PP2). In this region, participants took significantly longer to read the NP-attachment condition compared to the VP-attachment condition. This difference in reading times suggests that the visual context provided by the animation clips could shape the participants' expectations, guiding their parsing decisions towards a particular syntactic structure before the verb. However, the verb argument structure did not affect those parsing decisions until the verb itself was disclosed within the sentence. It could be because either the contextual cues could not activate the subcategorization information of the verb, or the activation was not strong enough and decayed before it could be linguistically mapped into a reading task.

As outlined by the residual activation mechanism (Pickering and Branigan, 1998), a lemma node and its relevant combinatorial nodes representing the subcategorization information are selected at the same time and syntactic priming occurs when an activated combinatorial node does not decay immediately. Additionally, the initial activation of syntactic rules has been claimed to occur when abstract word-level representations (lemma) encode syntactic information (Roelofs 1992, 1993; Levelt et al., 1999). If we regard the distinction observed between the VP- and NP-attachment types as indicative of activation of syntactic rules, it can be speculated that watching the animation clips could lead to the activation of a lemma node, however, this activation decayed before it could help interpret the structure presented in the sentences read following the clips. This is, of course, not surprising as previous comprehension studies also experienced early decay and stated that unlike production studies, they required shared content words to be able to initiate priming (Tooley and Traxler, 2010).

The finding that the visual context can distinguish between the processing of NP- and VP-attachment types both in verb-second (Shoghi et al., 2022) and verb-final ambiguous structures, suggests that as we observe the world around us, our language processing mechanism continues to operate concurrently and in parallel with our observations. This can subsequently deepen our understanding of why syntactic priming is more readily observed in production studies than in comprehension studies (see Tooley and Traxler, 2010). In other words, knowing the message beforehand, as is the case with production studies, provides the language processing mechanism with more time and resources and facilitates the processing of the target structure whereas in a comprehension task we need to build up a structure and discover the message as the sentence unfolds.

An interesting point, raised by an anonymous reviewer, is that the participants might have formulated a certain mental linguistic description of the events presented to them when they watched the video clips. It is reasonable to assume that these mental linguistic representations may have followed a simple matrix-clause SVO order (i.e., 'The boy hangs the coat on the hook') rather than a syntactically complex subject-relativization with a verb-final structure (i.e., 'The boy who the coat [ . . . ] hangs'). This is based on the idea that the participants may have opted for cognitive economy by generating simpler mental syntactic representations while processing events in the animated video clips. Therefore, it is plausible that the difference between the participants' expected syntactic structure and the verb-final sentences in our study might have led to a kind of discrepancy. Would this discrepancy then influence the potential syntactic priming effects in our data, however? Syntactic priming effects tend to be more pronounced when the word order in prime-target pairs is aligned, resulting in significantly faster responses to the targets (Bock and Griffin, 2000; Cleland and Pickering, 2003; Hartsuiker et al., 2008). Considering those accounts, the structural discrepancy between the mental syntactic form expected by our participants, which likely emerged in an SVO order, and the verb-final sentences used in our study, could, in fact, reduce the strength of potential syntactic priming effects. This reduction could occur because the syntactic processing demands differ between the two structures, making it less likely that the participants rely on the syntactic frame of the mental description when parsing the verb-final sentences. On the flip side, it is well-established that readers continuously reanalyze the syntactic form during online sentence processing (see e.g., Fodor and Ferreira, 1998). Therefore, rather than a pure discrepancy in expected and encountered structure leading to processing disruptions, we believe the participants needed to revise their mental syntactic form as they processed pre-critical segments during the self-paced reading task. This reanalysis mechanism most likely occurred at the relative pronoun *die* 'who' within the pre-critical region where the participants realized that they read a verb-final structure. Since we analysed reading times data from the beginning of the second prepositional phrase, as illustrated in Table 2 above,

potential impact of such a revision process on the processing of attachment ambiguity should be rather minimal. Furthermore, verb-final structures are not that infrequent in Dutch, and these structures seem to be acquired relatively early as they are often present in very young children's speech around the age of two (Jordens, 1990). Taken together, at this stage without future research which could directly investigate syntactic priming effects between verb-final and verb-second structures, we are not able to contemplate that the participants actually expected a simple SVO structure based on the animated video-clips before they read the critical sentences. Additionally, investigating whether participants' initial parsing decisions are influenced more by lexical-semantic content or by syntactic structure could provide valuable insights into the interplay between these factors in sentence processing. In our current study, we acknowledge that the observed effects of visual context on parsing decisions are likely mediated primarily by the lexical-semantic content rather than syntactic priming. This interpretation aligns with previous findings that visual context can strongly influence sentence comprehension by providing cues that guide the integration of lexical information (Tanenhaus et al., 1995).

In conclusion, utilizing a visually enhanced self-paced reading task, we demonstrated that presenting visual depictions of intended sentence meanings prior to reading can significantly impact initial parsing decisions in verb-final structures, especially in resolving PP-attachment ambiguities. While the design of this study does not permit a definitive conclusion, two plausible interpretations emerge. Consistent with prior research (e.g., Altmann and Steedman, 1988; Frazier, 1987; Spivey et al., 2002), one interpretation is that context can facilitate the processing of the preferred structures namely those representing the VP-attachment interpretation. Alternatively, context may introduce interference when it biases the parser towards non-preferred NP-attachment structures. These findings contribute to our understanding of the dynamic interplay between syntactic and contextual information, supporting constraint-based models of sentence processing, which posit that multiple sources of information are examined in parallel. Moreover, the absence of priming effects on argument structure processing highlights the challenges of activating and maintaining subcategorization information in comprehension tasks. Future research should further explore the extent to which visual context interacts with syntactic processing across different sentence structures and whether these interactions vary between comprehension and production tasks.

## CONFLICT OF INTERESTS STATEMENT

There are no conflicts of interest to disclose.

## CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

**Sara Shoghi:** Writing – review & editing, Writing – original draft, Conceptualization. **Seçkin Arslan:** Writing – review & editing, Supervision, Conceptualization. **Roelien Bastiaanse:** Writing – review & editing, Supervision, Conceptualization. **Srdan Popov:** Writing – review & editing, Resources, Funding acquisition, Conceptualization.

## Data availability

Data will be made available on request.

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## References

- Altmann, G.T., 2004. Language-mediated eye movements in the absence of a visual world: the 'blank screen paradigm'. *Cognition* 93, B79–B87. <https://doi.org/10.1016/j.cognition.2004.02.005>.
- Altmann, G.T., Kamide, Y., 2009. Discourse-mediation of the mapping between language and the visual world: eye movements and mental representation. *Cognition* 111, 55–71. <https://doi.org/10.1016/j.cognition.2008.12.005>.
- Altmann, G., Steedman, M., 1988. Interaction with context during human sentence processing. *Cognition* 30, 191–238. [https://doi.org/10.1016/0010-0277\(88\)90020-0](https://doi.org/10.1016/0010-0277(88)90020-0).



- Anwyl-Irvine, A.L., Massonnié, J., Flitton, A., Kirkham, N., Evershed, J.K., 2020. Gorilla in our midst: an online behavioral experiment builder. *Behav. Res. Methods* 52, 388–407. <https://doi.org/10.3758/s13428-019-01237-x>.
- Arai, M., Van Gompel, R.P., Scheepers, C., 2007. Priming ditransitive structures in comprehension. *Cogn. Psychol.* 54 (3), 218–250. <https://doi.org/10.1016/j.cogpsych.2006.07.001>.
- Bates, D., Maechler, M., Bolker, B.M., Walker, S., 2015. Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48. <https://doi.org/10.48550/arXiv.1406.5823>.
- Bock, J.K., 1986. Meaning, sound, and syntax: lexical priming in sentence production. *J. Exp. Psychol.: Learn. Mem. Cogn.* 12 (4), 575–586. <https://doi.org/10.1037/0278-7393.12.4.575>.
- Bock, K., Griffin, Z.M., 2000. The persistence of structural priming: transient activation or implicit learning? *J. Exp. Psychol.: General* 129 (2), 177–192. <https://doi.org/10.1037/0096-3445.129.2.177>.
- Boudewyn, M.A., Zirnstein, M., Swaab, T.Y., Traxler, M.J., 2014. Priming prepositional phrase attachment: evidence from eye-tracking and event-related potentials. *Quart. J. Exp. Psychol.* 67 (3), 424–454. <https://doi.org/10.1080/17470218.2013.815>.
- Branigan, H.P., Pickering, M.J., Cleland, A.A., 2000a. Syntactic co-ordination in dialogue. *Cognition* 75 (2), 13–25. [https://doi.org/10.1016/S0010-0277\(99\)00081-5](https://doi.org/10.1016/S0010-0277(99)00081-5).
- Branigan, H.P., Pickering, M.J., Stewart, A.J., McLean, J.F., 2000b. Syntactic priming in spoken production: Linguistic and temporal interference. *Mem. Cogn.* 28 (8), 1297–1302. <https://doi.org/10.3758/BF03211830>.
- Branigan, H.P., Pickering, M.J., McLean, J.F., 2005. Priming prepositional-phrase attachment during comprehension. *J. Exp. Psychol.: Learning Mem. Cogn.* 31 (3), 468–481. <https://doi.org/10.1037/0278-7393.31.3.468>.
- Britt, M.A., 1994. The interaction of referential ambiguity and argument structure in the parsing of prepositional phrases. *J. Mem. Lang.* 33, 251–283. <https://doi.org/10.1006/jmla.1994.1013>.
- Britt, M.A., Perfetti, C.A., Garrod, S., Rayner, K., 1992. Parsing in discourse: context effects and their limits. *J. Mem. Lang.* 31, 293–314. [https://doi.org/10.1016/0749-596X\(92\)90015-P](https://doi.org/10.1016/0749-596X(92)90015-P).
- Chambers, C.G., Tanenhaus, M.K., Magnuson, J.S., 2004. Actions and affordances in syntactic ambiguity resolution. *J. Exp. Psychol. Learn. Mem. Cogn.* 30, 687–696. <https://doi.org/10.1037/0278-7393.30.3.687>.
- Chang, F., Dell, G.S., Bock, K., Griffin, Z.M., 2000. Structural priming as implicit learning: a comparison of models of sentence production. *J. Psycholinguistic Res.* 29, 217–230. <https://doi.org/10.1023/A:1005101313330>.
- Cleland, A.A., Pickering, M.J., 2003. The use of lexical and syntactic information in language production: evidence from the priming of noun-phrase structure. *J. Mem. Lang.* 49 (2), 214–230. [https://doi.org/10.1016/S0749-596X\(03\)00060-3](https://doi.org/10.1016/S0749-596X(03)00060-3).
- Clifton Jr., C., Ferreira, F., 1989. Ambiguity in context. *Lang. Cogn. Process.* 4, S177–S103.
- Coopmans, C.W., Schoenmakers, G.J., 2020. Incremental structure building of preverbal PPs in Dutch. *Linguist. Neth.* 37 (1), 38–52. <https://doi.org/10.1075/avt.00036.coo>.
- Corley, M., Scheepers, C., 2002. Syntactic priming in English sentence production: categorical and latency evidence from an Internet-based study. *Psychon. Bull. Rev.* 9 (1), 126–131. <https://doi.org/10.3758/BF03196267>.
- Crain, S., Steedman, M., 1985. On not being led up the garden path: The use of context by the syntactic processor. In: Dowty, D.R., Kattunen, L., Zwicky, A.M. (Eds.) *Natural Language Parsing: Psychological, Computational and Theoretical Perspectives*. Cambridge University Press, Cambridge, England, pp. 320–358.
- Ferreira, F., Clifton, C., 1986. The independence of syntactic processing. *J. Mem. Lang.* 25 (3), 348–368. [https://doi.org/10.1016/0749-596x\(86\)90006-9](https://doi.org/10.1016/0749-596x(86)90006-9).
- Fodor, J., Ferreira, F., 1998. *Reanalysis in Sentence Processing*. Springer.
- Frazier, L., 1979. *On Comprehending Sentences: Syntactic Parsing Strategies*. University of Connecticut.
- Frazier, L., 1987. Syntactic processing: evidence from Dutch. *Nat. Lang. Linguist. Theory* 5, 519–559. <https://doi.org/10.1007/BF00138988>.
- Frazier, L., Rayner, K., 1982. Making and correcting errors during sentence comprehension: eye movements in the analysis of structurally ambiguous sentences. *Cogn. Psychol.* 14, 178–210. [https://doi.org/10.1016/0010-0285\(82\)90008-1](https://doi.org/10.1016/0010-0285(82)90008-1).
- Garnsey, S.M., Pearlmutter, N.J., Myers, E., Lotocky, M.A., 1997. The contributions of verb bias and plausibility to the comprehension of temporarily ambiguous sentences. *J. Mem. Lang.* 37, 58–93. <https://doi.org/10.1006/jmla.1997.2512>.
- Hartsuiker, R.J., Bernolet, S., Schoonbaert, S., Speybroeck, S., Vanderelst, D., 2008. Syntactic priming persists while the lexical boost decays: Evidence from written and spoken dialogue. *J. Mem. Lang.* 58 (2), 214–238.
- Hartsuiker, R.J., Kolk, H.H., 1998. Syntactic persistence in Dutch. *Lang. Speech* 41 (2), 143–184. <https://doi.org/10.1177/00238309980410020>.
- Huetttig, F., Rommers, J., Meyer, A.S., 2011. Using the visual world paradigm to study language processing: a review and critical evaluation. *Acta Psychol.* 137, 151–171. <https://doi.org/10.1016/j.actpsy.2010.11.003>.
- Jordens, P., 1990. The acquisition of verb placement in Dutch and German. *Linguistics* 28 (6), 1407–1448. <https://doi.org/10.1515/ling.1990.28.6.1407>.
- Just, M.A., Carpenter, P.A., Woolley, J.D., 1982. Paradigms and processes in reading comprehension. *J. Exp. Psychol.: General* 111 (2), 228–238. <https://doi.org/10.1037/0096-3445.111.2.228>.
- Ledoux, K., Traxler, M.J., Swaab, T.Y., 2007. Syntactic priming in comprehension: evidence from event-related potentials. *Psychol. Sci.* 18 (2), 135–143. <https://doi.org/10.1111/j.1467-9280.2007.0186>.
- Levelt, W.J., Roelofs, A., Meyer, A.S., 1999. A theory of lexical access in speech production. *Behav. Brain Sci.* 22 (1), 1–38. <https://doi.org/10.1017/S0140525X99001776>.

- MacDonald, M.C., 1994. Probabilistic constraints and syntactic ambiguity resolution. *Lang. Cogn. Processes* 9, 157–201. <https://doi.org/10.1080/01690969408402115>.
- McRae, K., Matsuki, K., 2013. Constraint-based models of sentence processing. *Sentence Process.* 519, 51–77. <https://doi.org/10.4324/9780203488454>.
- McRae, K., Spivey-Knowlton, M.J., Tanenhaus, M.K., 1998. Modeling the influence of thematic fit (and other constraints) in online sentence comprehension. *J. Mem. Lang.* 38, 283–312. <https://doi.org/10.1006/jmla.1997.2543>.
- Mitchell, D.C., Cuetos, F., Corley, M.M., Brysbaert, M., 1995. Exposure-based models of human parsing: Evidence for the use of coarse-grained (nonlexical) statistical records. *J. Psycholinguist. Res.* 24 (6), 469–488.
- Pickering, M.J., Branigan, H.P., 1998. The representation of verbs: evidence from syntactic priming in language production. *J. Mem. Lang.* 39 (4), 633–651. <https://doi.org/10.1006/jmla.1998.2592>.
- Potter, M.C., Lombardi, L., 1998. Syntactic priming in immediate recall of sentences. *J. Mem. Lang.* 38 (3), 265–282. <https://doi.org/10.1006/jmla.1997.2546>.
- R Core Team, 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Rayner, K., Garrod, S., Perfetti, C.A., 1992. Discourse influences during parsing are delayed. *Cognition* 45, 109–139. [https://doi.org/10.1016/0010-0277\(92\)90026-E](https://doi.org/10.1016/0010-0277(92)90026-E).
- Reitter, D., Keller, F., Moore, J.D., 2011. A computational cognitive model of syntactic priming. *Cogn. Sci.* 35 (4), 587–637. <https://doi.org/10.1111/j.1551-6709.2010.01165.x>.
- Roelofs, A., 1992. A spreading-activation theory of lemma retrieval in speaking. *Cognition* 42 (1–3), 107–142. [https://doi.org/10.1016/0010-0277\(92\)90041-F](https://doi.org/10.1016/0010-0277(92)90041-F).
- Roelofs, A., 1993. Testing a non-decompositional theory of lemma retrieval in speaking: retrieval of verbs. *Cognition* 47 (1), 59–87. [https://doi.org/10.1016/0010-0277\(93\)90062-Z](https://doi.org/10.1016/0010-0277(93)90062-Z).
- Shadish, W.R., Cook, T.D., Campbell, D.T., 2002. *Experimental and Quasi-experimental Designs for Generalized Causal Inference*. Houghton Mifflin.
- Shoghi, S., Arslan, S., Bastiaanse, R., Popov, S., 2022. Does a walk-through video help the parser down the garden-path? A visually enhanced self-paced reading study in Dutch. *Front. Psychol.* 13, 1–14. <https://doi.org/10.3389/fpsyg.2022.1009265>.
- Snedeker, J., Trueswell, J.C., 2004. The developing constraints on parsing decisions: the role of lexical-biases and referential scenes in child and adult sentence processing. *Cogn. Psychol.* 49, 238–299. <https://doi.org/10.1016/j.cogpsych.2004.03.001>.
- Spivey, M.J., Tanenhaus, M.K., Eberhard, K.M., Sedivy, J.C., 2002. Eye movements and spoken language comprehension: effects of visual context on syntactic ambiguity resolution. *Cogn. Psychol.* 45, 447–481. [https://doi.org/10.1016/S0010-0285\(02\)00503-0](https://doi.org/10.1016/S0010-0285(02)00503-0).
- Staub, A., 2007. The parser doesn't ignore intransitivity, after all. *J. Exp. Psychol.: Learn. Mem. Cogn.* 33, 550–569. <https://doi.org/10.1037/0278-7393.33.3.550>.
- Sturt, P., Pickering, M.J., Crocker, M.W., 1999. Structural change and reanalysis difficulty in language comprehension. *J. Mem. Lang.* 40, 136–150. <https://doi.org/10.1006/jmla.1998.2606>.
- Tanenhaus, M.K., Spivey-Knowlton, M.J., Eberhard, K.M., Sedivy, J.C., 1995. Integration of visual and linguistic information in spoken language comprehension. *Science* 268 (5217), 1632–1634. <https://doi.org/10.1126/science.7777863>.
- Taraban, R., McClelland, J.L., 1988. Constituent attachment and thematic role assignment in sentence processing: influences of content-based expectations. *J. Mem. Lang.* 27, 597–632. [https://doi.org/10.1016/0749-596X\(88\)90011-3](https://doi.org/10.1016/0749-596X(88)90011-3).
- Thothathiri, M., Snedeker, J., 2008a. Give and take: syntactic priming during spoken language comprehension. *Cognition* 108 (1), 51–68. <https://doi.org/10.1016/j.cognition.2007.12.012>.
- Thothathiri, M., Snedeker, J., 2008b. Syntactic priming during language comprehension in three- and four-year-old children. *J. Mem. Lang.* 58 (2), 188–213. <https://doi.org/10.1016/j.jml.2007.06.012>.
- Tooley, A.J., Gilden, J., Jacobelli, J., Beemiller, P., Trimble, W.S., Kinoshita, M., Krummel, M.F., 2009. Amoeboid T lymphocytes require the septin cytoskeleton for cortical integrity and persistent motility. *Nat. Cell Biol.* 11 (1), 17–26. <https://doi.org/10.1038/ncb1808>.
- Tooley, K.M., Traxler, M.J., 2010. Syntactic priming effects in comprehension: a critical review. *Language and Linguistics Compass* 4 (10), 925–937. <https://doi.org/10.1111/j.1749-818X.2010.00249.x>.
- Traxler, M.J., 2008. Lexically independent priming in online sentence comprehension. *Psychon. Bull. Rev.* 15 (1), 149–155. <https://doi.org/10.3758/PBR.15.1.149>.
- Traxler, M.J., Tooley, K.M., 2008. Priming in sentence comprehension: strategic or syntactic? *Lang. Cogn. Processes* 23 (5), 609–645. <https://doi.org/10.1080/01690960701639898>.
- Trochim, W.M.K., 2006. *Research Methods Knowledge Base*. Atomic Dog Publishing.
- Trueswell, J.C., Tanenhaus, M.K., Kello, C., 1993. Verb-specific constraints in sentence processing: separating effects of lexical preference from garden-paths. *J. Exp. Psychol. Learn. Mem. Cogn.* 19, 528–553. <https://doi.org/10.1037/0278-7393.19.3.528>.
- Trueswell, J.C., Tanenhaus, M.K., Garnsey, S.M., 1994. Semantic influences on parsing: use of thematic role information in syntactic ambiguity resolution. *J. Mem. Lang.* 33, 285–318. <https://doi.org/10.1006/jmla.1994.1014>.
- Witzel, N., Witzel, J., Forster, K., 2012. Comparisons of online reading paradigms: eye tracking, moving-window, and maze. *J. Psycholinguist. Res.* 41, 105–128. <https://doi.org/10.1007/s10936-011-9179-x>.