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Processing correlates of verb typologies: Investigating internal structure and argument realization

Abstract: The paper investigates the processing correlates of core verb features used to generate verb typologies. The aim was to contrast the effects of verb internal structure (as in semantic/conceptual features e.g., Jackendoff [1991]; Levin and Rappaport Hovav [2005]) with argument structure and argument realization in sentence processing. To this end, we designed a self-paced reading task with internal structure and argument realization as variables in verb processing. Results showed that absence of a prototypical *Agent* or mismatch between thematic hierarchies and argument realization yields longer processing times possibly due to some form of thematic reanalysis or as a reaction to a "surprise" effect by the human processor while detecting a non-expected thematic assignment. No effects of verb internal structure were found. We take this result as an indication that argument structure and argument realization play an important role in verb recognition during sentence processing. We further propose that this reflects their prominent role in verb representation and we suggest that this finding could give additional support to verb classifications based on verb argument structure features compared to those based on internal structure.

Keywords: verb classes, argument realization, argument structure, internal structure, self-paced reading, sentence processing

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1 Introduction

Verb classifications, i.e., groupings of verbal predicates according to their properties, are of great interest to both theoretical and computational linguistics as well as to psychology. In theoretical and computational linguistics, verb typologies have contributed to our understanding of both semantic and syntactic properties of the language faculty – with particular attention to the distributional and cross-linguistic regularities exhibited by classes of events and states. In psychology, these classes are important because they help us understand how events are conceptualized and represented in the brain, as well as how they are used in linguistic processing and by other cognitive functions. The majority of verb classifications are based either on common meaning components (e.g., Koenig and Davis 2001; Korhonen et al. 2003), or on syntactic properties of verbs (Sun et al. 2008; Merlo and Stevenson 2002; Schulte im Walde and Brew 2002), while others are situated at the interface, making reference to crucial verb properties that involve both the syntax and the semantics of the verbs (Jackendoff 1991; Levin 1993; Dang et al. 1998; Dorr 1997; Merlo and Stevenson 2001).

Since the ultimate goal of verb classifications is to predict their linguistic behavior, in this paper we address the question of the status of verb classifications in the mental representation of grammar and meaning. In other words, the question we pose is which facets of verb classifications the human language processing mechanism might be tuned to during language comprehension. Our aim is to seek evidence on the psychological reality of verb properties used to generate verb typologies and to examine whether, based on specific classifications, one could predict processing correlates, especially at the sentence level. This approach reflects our assumption that theoretical claims about verb typologies cannot dispense with psycholinguistic evidence on verb classes – a view which certainly does not reflect the consensus in linguistics.

The use of behavioral experiments to inform verb classifications is not new and it has been widely used in computational linguistics, corpus-based studies and Natural Language Processing. Schulte im Walde and colleagues (Schulte im Walde and Melinger 2005; Schulte im Walde 2006; Schulte im Walde et al. 2007) have conducted human association experiments in order to identify salient features to induce semantic verb classes and also to discover verb properties that appear to be crucial to verb meaning for native speakers. In a similar way, the present study seeks to inform verb classifications by contributing data from native speakers' processing of various verb features.

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2 Overview of verb features that give rise to verb classifications

2.1 Internal (semantic) structure

Despite the controversy as to what is the best way to classify verbs (see Levin 2010), perhaps the most common method for doing so is to rely on their purported internal (semantic) structure. This method assumes that verbs are decomposable into bundles of features or components, with common components between verbs serving as the primary source of classifications. A typical distinction is between *events* and *states* (e.g., Davidson 1971; Dowty 1979; Jackendoff 1991; Rappaport Hovav and Levin 2005). While events entail one or several changes from an initial situation to a resulting one (*destroy*, *build*, *bake*), states entail a single stable situation (*love*, *belong*, *contain*). Moreover, the features that are constituents of eventive verbs are usually thought to be simpler conceptual units such as CAUSE, BECOME, GO or CHANGE and resulting STATES, while stative verbs are usually thought to be semantically simplex. In other words, events differ from states in their encoding of sub-situations and changes. Thus, in summary, according to this approach, a key difference between lexical meanings of events and states is whether or not the meaning of the verb denotes a *change of state* (CS), with those verbs denoting CS being considered semantically more *complex*.

2.2 Argument structure

Argument structure (A-structure) is the representation of the number and the type of the arguments of a verb. In other words, A-structure encodes a verb's obligatory arguments and the assignment of thematic roles to the constituents (noun phrases, prepositional phrases, even clauses) that represent the participants in actions, states, or events that a verb's carrier sentence denotes. For instance, while *sleep* has only one argument, a sleeper, the transitive *break* has two, a breaker and something broken. Furthermore, it is the A-structure of these verbs that determines that the single argument of *sleep* is an *Experiencer* and the arguments of *break* are an *Agent* and a *Theme*. A-structure is not totally independent from the semantic properties of a verb. For instance, the verbs *kill* and *love* are different in terms of semantic complexity, one being an event and the other being a state. This difference is also reflected in terms of their A-structure since while both require the presence of two arguments, in the case of *kill* these are an *Agent* and a *Patient*, while in the case of *love* these are an *Experiencer* and a *Theme*.

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Notice that because arguments are structurally determined – thus, syntactic – positions, they are not "conceptual" in nature, i.e., they have no bearing on the truth value of a given utterance: thus, *The sofa drank the juice* would have, in principle, *The sofa* as *Agent* regardless of its real-world plausibility. The contribution that these thematic labels make is discussed below (see Section 2.3).

2.3 Argument realization

Argument realization refers to possible syntactic expressions of arguments of verbs (Levin and Rappaport Hovav 2005). That is, argument realization bears on the possible mapping(s) between structurally determined arguments of a verb and the syntactic constituents of a sentence. A theoretical construct that has figured prominently in a wide range of approaches to argument realization is *thematic hierarchy*. Thematic hierarchy establishes prominence relationships among the arguments of a verb and allows a particular argument to be referred to in terms of its relative position (e.g., subject vs. object), instead of in terms of its semantic role. While a thematic hierarchy is a theoretical construct intended to overcome the limitations of traditional individual semantic roles, one of the main problems with it is that there is no agreement among linguists about what would be the *correct* thematic hierarchy: while there have been several proposed hierarchies, there is considerable controversy in the ranking of various thematic roles (see Manouilidou and de Almeida 2009 for discussion).

For instance, Fillmore (1968: 33) suggests that the order is *Agent* > *Instrument* > *Theme*/*Patient*, meaning that whenever there is an *Agent* in the sentence, it occupies the subject position; and in the absence of an *Agent* it is the *Instrument* that occupies the subject position; otherwise the subject is the *Theme* or *Patient*. Various thematic hierarchies have been proposed, among others, by Baker (1989, 1997), Givón (1984), Grimshaw (1990), Kiparsky (1985), Van Valin (1990). However, although there is considerable variability in the ranking of various thematic roles; the only point of agreement found among them is the fact that whenever there is an *Agent*, it occupies the subject position. Thus, in a *canonical* thematic hierarchy, the *Agent* thematic role undoubtedly occupies the most prominent position in the sentence. Consequently, any thematic hierarchy lacking the *Agent* thematic role would be considered *atypical*. For instance, in a sentence such as *The toddler fears the dog*, the ranking of the thematic roles goes as follows: *Experiencer* (the toddler, i.e., the one who experiences fear) > *Theme* (the "object" or "stimulus" that causes fear to the Experiencer). Another possibility of argument realization has to do with cases of mismatch between what the hierarchy determines and the actual realization, such as in cases of Object-*Experiencer* verbs

where the *Theme*/*Stimulus* argument features before the *Experiencer*, such as in the sentence *The dog frightened the toddler*. In this case, we talk about *non-canonical* argument realization.

Given the great variability in hierarchies and their specific thematic roles, the notion of Proto-role (Dowty 1991) seems to be particularly useful. A Proto-role is the prototypical instance of every thematic role. For instance, a Proto-*Agent* is the ideal, exemplary *Agent*. This entails the properties of volition, animacy, intentionality, and sentience. Based on these properties, a Proto-Agent could include the roles of *Agent*, *Causer, Experiencer*, and *Possessor*. Similarly, a Proto-*Patient* (Undergoer) includes the roles of *Patient*, *Causee*, *Stimulus*, and *Possessed* (Primus 1999). These Proto-roles create certain dependencies in the sentence. Based on its semantic properties and on its position in the sentence, a specific NP is more likely to bear a certain Proto-role which immediately affects the way we perceive the following NP. For instance, when the processor encounters an animate NP in the subject position, then it tends to "temporarily" assign to it the *Agent* Proto-role with the consequence of assigning the *Patient* Proto-role to the following NP[1]. This processing strategy will be further described in Section 3.4.

3 Psycholinguistic background

In this section we present experimental evidence for and against the importance of the above verb properties in verb processing.

3.1 Processing of internal structure

Experimental evidence with respect to the processing of internal (semantic) structure is controversial. Several psycholinguistic studies, employing a variety of techniques, have failed to support the idea that verbs are represented in terms of complex semantic templates or structures (de Almeida 1999; de Almeida and Dwivedi 2008; J. Fodor et al. 1975; Fodor et al. 1980; Kintsch 1974; Mobayyen and de Almeida 2005; Rayner and Duffy, 1986). Most of these studies compared lexical causatives (e.g., *kill*) with other transitives such as perception verbs (e.g., *hear*) which, under all analyses, are taken to be represented by simplex (template) structures. These studies found no significant processing differences between

1 Although we cannot fully adopt Dowty's (1991) view, we take it to have a heuristic value for the purpose of laying out the variables used in verb classification, as investigated in the present paper. This will become clear in the discussion.

hypothetically complex and simplex verb classes, suggesting instead that they are all semantically simplex – baring cases of verbs that are also morphologically complex. In contrast, Gennari and Poeppel (2003) have shown that in lexical decision and self-paced reading tasks, stative verbs are recognized faster than eventive verbs (a difference of about 23 milliseconds), a fact that the authors interpret as consistent with the effect of semantic complexity: events being more complex than states. Moreover, McKoon and Macfarland (2002) found a difference between externally and internally caused change of state, as in *crumble* and *rot*, respectively. They argued that longer sentence acceptability judgment times for externally caused events reflect the extra computation necessary to unpack the greater number of meaning constituents carried by externally caused change of state verbs. Thus, the issue of semantic complexity requires further investigation: is internal structure – and, by extension, verb classifications based on it – a good predictor for verb behavior during language processing?

3.2 Processing argument structure

Several studies dealing with on-line sentence comprehension have suggested that lexical properties such as thematic roles and A-structure are immediately accessed by the processor when the verb is encountered (e.g., Altmann and Kamide 1999; MacDonald et al. 1994; Trueswell et al. 1994). Linguistic constraints and more specifically verb arguments play a privileged role in language comprehension by introducing entities into the discourse. A verb is said to project its arguments before they are explicitly mentioned (Boland 2005; Pickering and van Gompel 2006). Based on this line of evidence, researchers have further postulated that each verb in the lexicon specifies how its thematic roles map onto grammatical relations, which are then marked in syntax by word order or morphological case, according to the principles of the language, thus constituting part of linguistic representation (Bencini and Goldberg 2000; Friederici and Frisch 2000).

Another major question about verb processing is whether native speakers are sensitive to the various verb classes on the basis of their A-structure, that is, on the basis of shared semantic and syntactic properties.[2] This question is crucial

2 For example, the sentence *Beth got Liz an invitation,* in terms of verb meaning, is related to the phrase *Michelle got the book*. However, in terms of verb A-structure, it is more related to the phrase *Paula took Sue a message,* both being ditransitive constructions. Similarly, *Laura got the ball into the net* in terms of argument structure is related to *Pat threw the keys onto the roof* (both "caused motion" constructions). Do native speakers rely on the argument structure configuration in determining sentence meaning?

to support the existence of a stored representation of verb-specific information, and also crucial to verb typologies as predictors for verb behavior. Bencini and Goldberg (2000) demonstrated that types of complement configurations are directly associated with sentence meaning, confirming that native speakers respect both syntactic information and verb classes. Finally, Friederici and Frisch (2000), in an ERP study investigating brain activation in different types of violations of A-structure, demonstrated the special status of thematic information carried by the verb by showing that structural and thematic aspects encoded in the verb are processed differently, possibly supported by different brain systems. Similarly, it has been shown that aphasic patients have difficulties with verbs with multiple A-structures as well as with verbs with more than one argument (English: Kim and Thompson 2000, 2004; Italian: Luzzatti et al. 2002; German: De Bleser and Kauschke 2003). Thus, in contrast with evidence from internal structure processing, it appears that A-structure properties constitute a safe predictor when it comes to verb behavior in sentence processing.

3.3 Argument realization

A number of studies have shown that it is not merely the syntactic features of a verb that affect its processing, but the process of "linking" the semantic representation to syntactic positions. Ferreira (1994) emphasizes the importance of argument realization in the participants' choice between active and passive sentences. The same study has shown that with agentive verbs, native speakers tend to prefer actives, while with object-*Experiencer* verbs, they have some tendency to prefer passives, so that the most prominent argument, in terms of thematic hierarchy (the *Experiencer* in this case), figures in the subject position. In a more recent paper, Ferreira (2003) brings to light another dimension, this one of the interaction of argument realization with parsing and interpretation heuristics – something that we address below. Apart from that, the literature on language deficits of neurologically damaged populations is full of cases of aphasic patients that have difficulties with non-canonical argument realization, either as by-product of syntactic movement (passives, object relative clauses) or from verbs' inherent properties (i.e., in the case of psychological predicates). For instance, Piñango (2006) postulates that agrammatic patients experience difficulties with passives and *psych* verbs due to the fact that these structures deviate from the canonical argument realization. Similar results have been reported by Manouilidou et al. (2009) who investigated the nature of the verb deficit in Alzheimer's disease with a special focus on thematic role assignment. Manouilidou et al. employed verbs whose argument realization follows canonical thematic hierarchy, with *Agent*

and *Theme* as main roles (e.g., *The hunter killed the deer*), and verbs whose argument realization deviates from canonical hierarchy, such as *psych* verbs (e.g., *fear, frighten*). The study showed that Alzheimer's patients performed worse than controls in *psych* verb sentences, demonstrating greater difficulty with object-*Experiencer* sentences. The difference was taken to reflect a difficulty with structures deviating from canonical realization.

3.4 Thematic reanalysis and the (extended) Argument Dependency Model

Closely related to processing A-structure and argument realization is the Argument Dependency Model (ADM) (Bornkessel 2002; Bornkessel et al. 2002, 2003) and its more recent *extended* version (eADM; Bornkessel and Schlesewsky 2006; 2008). Both versions try to capture fine grain details of processing when dealing with hierarchy mismatches in sentence comprehension. More specifically, the ADM model postulates that on-line sentence comprehension takes place incrementally and that hierarchical thematic dependencies are immediately set, even before the verb is encountered. Thus, thematic preferences give rise to the initial argument being interpreted as thematically higher ranking. When there is a discrepancy between the thematic structure and the hierarchical thematic relations established between the arguments before the processing of the verb, then *thematic reanalysis* is initiated. Empirical data from a series of ERP experiments in German (Bornkessel 2002; Bornkessel et al. 2002, 2003) support the basic idea of the model. Following the general idea of Friederici's (1995, 1999, 2002) neurocognitive model of language processing, ADM assumes three stages of sentence processing, which apply sequentially in time. Within stage 1, very basic processes of constituent structuring apply, involving word category processing. Stage 2 consists of mechanisms responsible for the establishment of higher-level (viz., syntactic or thematic) relations between sentential constituents. Finally, in stage 3, all of the information types processed separately during stage 2 are integrated with one another and reanalysis processes are initiated if necessary. It is during stage 3 that thematic reanalysis takes place, when the conceptual representations built during stage 2 cannot be confirmed due to mismatch between morphological and hierarchical information.

The model assumes that the form-meaning mapping during real-time sentence comprehension proceeds via two distinct processing pathways, thereby differing in the degree of meaning computed incrementally. One route refers to the syntactic processing and the other to the thematic processing. A crucial factor that appears to determine which path to follow is morphological marking. Un-

ambiguously case marked arguments are processed via the thematic pathway (see 1a below), whereas case-ambiguous arguments are processed via the syntactic pathway (as in 1b).

(1) a. . . . dass der Lehrer den Vater . . .
. . . that [the teacher]NOM [the father]ACC . . .
b. . . . dass Dietmar Tänzerinnen . . .
. . . that DietmarNOM/ACC/DAT dancersNOM/ACC/DAT . . .
(Schlesewsky and Bornkessel 2004).

Apart from morphological marking, animacy also seems to be related to the thematic pathway. Consider the ungrammatical sentences in (2) from Schlesewsky and Bornkessel (2004). Although equally ungrammatical, the sentences in (2) differ with respect to the animacy of the NP that introduces ungrammaticality. For instance, in sentence (2a) the NP *the bishop* is [+animate], while in sentence (2b) the NP *the twig* is [–animate].

(2) a. . . . welcher Mönch der Bischof begleitete.
. . . [which monk]NOM [the bishop]NOM accompanied
b. . . . welcher Mönch der Zweig streifte.
. . . [which monk]NOM [the twig]NOM brushed

Bornkessel and colleagues have shown that thematic reanalysis becomes necessary when the original interpretation of the initial argument as thematically highest-ranking must be revised (Bornkessel et al. 2003). They conclude that case-marking languages such as German may employ non-syntactic processing routes to determine the thematic interpretation of a sentence.

The revised version of ADM, the eADM, also assumes incremental interpretation and postulates three phases of core constituent processing, but it crucially leaves room for other factors that interfere in online comprehension, such as the *role prototypicality* of the arguments. In such a model, the potential role of prototypicality of an argument may guide the choice of syntactic structure, hence influencing the role *identification*. The model postulates that incremental interpretation involves the assignment of the generalized semantic roles "actor" and "undergoer", which are formulated along the lines of Dowty's proto-roles. These roles are assigned to arguments on the basis of prominence information. A prototypical "actor" (to be interpreted as "Agent") should bare the characteristics of control, sentience, causation (Bornkessel and Schlesewsky 2008). Based on a series of EEG, eye-tracking and behavioral experiments, the authors interpret their results as evidence that role *prototypicality* (i.e., prototypicality of subject)

determines the ease with which the processor assigns thematic roles to certain NPs and also the difficulty with which it abandons its original preference. The principles of the ADM and eADM, which emphasize the importance of thematic roles in sentence processing, will be further discussed in the interpretation of the results of the present study.

4 The present experiment

The goal of our experiment was to contrast the roles of verb-internal (semantic) structure, A-structure and argument realization in sentence comprehension in order to investigate whether we can establish primacy relationships between them. In particular, we examined the reading-time (RT) performance of native speakers of English with respect to four groups of verbs that differ with respect to their internal structure (change-of-state [+CS] vs. non-stage-of-state [–CS] verbs) and their thematic-role assignment properties which might result in non-canonical argument realization (Agent [+AG] vs. Non-Agent [–AG]).

4.1 Predictions

Our specific processing predictions take into account previous findings from studies on verb-semantic processing (e.g., Fodor et al. 1980; Gennari and Poeppel 2003) as well as the claim that the processor tends to reanalyze thematic properties of arguments when the canonical thematic requirements are not met (e.g., the eADM; Bornkessel and Schlesewsky 2008).

According to Gennari and Poeppel (2003) and McKoon and MacFarland (2002) we should expect verbs that denote [+CS] to yield longer RTs. By contrast, according to Fodor (1998) and de Almeida (1999), we should expect no difference between verbs that denote [+CS] or [–CS]. These studies do not mention anything about agentivity – for their concern is only the semantic properties of verbs – thus we cannot formulate any predictions about this feature based on their approach. In addition, according to Ferreira (1994; 2003), Bornkessel and colleagues and also the literature of pathological populations (c.f. Manouilidou et al. 2009 and Piñango 2006), verbs with non-canonical argument realization should be harder to process and they should trigger thematic reanalysis. Moreover, although Gennari and Poeppel (2003) do not predict any difference between [+CS] sentences, the reanalysis model predicts different degrees of complexity for sentences that are [–AG] such as object-*Experiencer* (e.g., *frighten*) and subject-*Experiencer* (e.g., *love*); not only do object-*Experiencer* sentences are of the type [–AG] but they also

Table 1: Studies on verb processing and their predictions (">" denotes longer reading times)

Study	Predictions		
Gennari and Poeppel (2003), McKoon and Macfarland (2002)	+CS, +AG (*kill*) +CS, –AG (*frighten*)	>	–CS, +AG (*kiss*) –CS, –AG (*love*)
Fodor (1998), de Almeida (1999)	No difference between +CS and –CS		
Ferreira (1994; 2003) Bornkessel and Schlesewsky (2008) Manouilidou et al. (2009) Piñango (2006)	–AG, +CS (*frighten*) –AG, –CS (*love*)	>	+AG, +CS (*kill*) +AG, –CS (*kiss*)

involve a mismatch in thematic realization, with the *Stimulus* argument preceding the *Experiencer*. These predictions are presented schematically in Table 1, with longer reading times representing greater processing difficulty.

5 Method

5.1 Participants

Thirty-seven undergraduate students participated in the study for course credit. They were all native speakers of English and had normal or corrected-to-normal vision.

5.2 Materials and design

Materials included 128 sentences, divided into four conditions, according to the variables of change of state (+/–CS) and agentivity (+/–AG). These sentences formed 32 sets such as the one presented in (3) (see Appendix for the full set of materials). All sentences had the same basic structure, Det1+NP1+Adv+V+Det2+NP2. Each condition included a distinct type of verb, in order to achieve as much homogeneity as possible. For instance, for condition [+CS, +AG] we employed lexical causatives, e.g., *kill*, *destroy*, *crush*, etc. while for condition [+CS, –AG] we employed psychological object-Experiencer verbs, such as *frighten*, *scare*, *anger*. Similarly, for condition [–CS, +AG] we employed non-causative agentive transitive verbs, such as *follow*, *hit*, *kick*, etc. while for the [–CS, –AG] condition we employed either perception, mental or psychological verbs, all belonging to the category of subject-Experiencer verbs, such as *sense*, *smell*, *love*, etc. The inclusion of adverbs served an important purpose. We employed mostly

manner, and in few cases, degree adverbs in an attempt to affect the volition and intentionality of NP1. For instance, in the +AG conditions (3a) and (3c) we only employed manner adverbials that describe a volitional act (*carefully*, *firmly*) in order to stress volition and intentionality and enforce an agentive reading in these conditions. In contrast, for the –AG conditions we either used manner adverbs that cancel out volition such as *unintentionally*, *accidentally*, etc., in [+CS, –AG] condition or manner and degree adverbials in [–CS, –AG] condition such as *completely*, *hardly*. The adverb-induced manipulation was particularly important in condition [+CS, –AG] (3b) which, without the adverb, could denote an intentional act on the part of the *Causer* of, e.g., the *fright* state of sentence (3b), thus making condition [+CS, –AG] indistinguishable from condition [+CS, +AG]. Finally, the use of adverbs ensured that the structure and length of all sentences in all four conditions was kept constant.

(3) a. The hunter maliciously killed the bear (+CS,+AG, lexical causative)
b. The hunter unintentionally frightened the bear (+CS, –AG, object-*Experiencer*)
c. The hunter persistently followed the bear (–CS, +AG, agentive transitive)
d. The hunter barely sensed the bear (–CS, –AG, subject-*Experiencer*)

The above classification, that is, the specific combination of verbs of various semantic content as well as their combination with specific adverbs, could be seen as leading to heterogeneity of the experimental materials. It is true that the [+CS, +AG] condition contains verbs of "physical change", verbs of "mental state" and also verbs with "lexicalized agency".[3] However, this classification results from a strict *change-of-state* approach, according to which factors such as *mental* vs. *physical* state are not relevant, for they can both be represented by similar semantic templates (e.g., as in Levin and Rappaport-Hovav 2005). The same heterogeneity could be seen with the adverbials used in each condition, since they modify the events denoted by their carrier sentences in different ways. However, the use of specific adverbials in each condition was part of the design and the key factor for determining the actual character of each condition. That is, on the one hand we wanted to force a non-intentional, "non-eventive" reading in condition [+CS, –AG], and on the other, an intentional "eventive" reading in condition [+CS, +AG] in order to manipulate the agentive prototypicality of NP1. While this manipulation lead us to employ adverbs that differ in terms of morphological complexity

3 We thank an anonymous reviewer for the observation of "lexicalized agency".

– with the ones used for [+CS, –AG] being more complex – this variable was taken into account in the items analyses (see Section 6).

Sentences were divided into four lists, with each list containing 32 sentences, eight sentences from each of the four conditions. Each participant only saw one of these lists, thus each participant was exposed to one sentence of each of the 32 quadruples (as in (3a)–(3d)). The experiment also included 64 filler sentences with diverse types of syntactic and semantic structures.

5.3 Procedure

We employed a self-paced reading moving window paradigm (Just et al. 1982), which is widely used in psycholinguistics. This paradigm measures reading times as readers control via button press the presentation duration of a given word or sentence segment on the screen. Reading latencies are thought to reflect the properties of the words or segments being read – or already read – and generally correlate with the time course of the linguistic and cognitive processes involved in reading and comprehension. Studies have shown that the moving-window version of this paradigm closely resembles natural reading, often replicating the results of eye-tracking data (see Binder and Rayner 1998).

Participants were first presented with a row of dashes on the screen. Each dash represented a letter in the to-appear sentence (such as "--- ------ ---------- ------ --- ----" for sentence (3a)). They were told that each time they pressed the space bar on the computer keyboard, a word would appear in place of the dashes and, as each new word appeared, the previously presented word would turn back to a set of dashes. Participants were instructed to read sentences at a normal pace. The experiment was run on Apple Macintosh computers running PsyScope (Cohen et al. 1993).

6 Results and discussion

Reading times (RTs) for all six sentence segments (Det1, N1, Adv, V, Det2, and N2) for each of the four sentence types ([+CS, +AG], [+CS, –AG], [–CS, +AG], and [–CS, –AG]) constituted the data for analyses. For the items analyses, the data were the means of each of the six segments of each sentence type constituting the 32 sentence quadruples. Due to errors in the script files, data from 14 sentences had to be removed from the raw data. Six of these sentences were from the [+CS, +AG] condition, three were from the [+CS, –AG] and [–CS, +AG] conditions each, and one was from the [–CS, –AG] condition. Also, one sentence of the type [–CS, –AG]

was not presented to the subjects. For the items analyses, missing values due to the 15 eliminated or missing sentences from the raw dataset were replaced with the mean of each condition at each segment (11.7% of all averaged cells). Raw data from the remaining 113 sentences were analyzed for outliers. RTs two standard deviations below or above the mean for each condition were replaced with the cutoff values (4.2% of the data). Analyses took into account subjects (*F1*, *t1*) and items (*F2*, *t2*) as random variables.

Figure 1 depicts RTs for all four sentence types and segments. As can be seen, [+CS, −AG] differs markedly from the other three sentence types beginning at the Adverb position and continuing to the Verb position. A 4 (sentence type) × 6 (sentence segment) repeated measures ANOVA showed a significant main effect of sentence type in the subjects analysis, $F1$ (3, 108) = 2.82, p = .042, but not in the items analysis, $F2$ (3, 93) = 0.65, p = .59. There was also a significant main effect of sentence position, $F1$ (5, 180) = 37.2, p < .0001, $F2$ (5, 155) = 191.8, p < .0001, and an interaction between sentence type and position in both subjects and items analyses, $F1$ (15, 540) = 3.21, p < .0001, $F2$ (15, 465) = 1.89, p = .022.

Following up on the main effect of sentence type and the interaction between sentence type and sentence position, we conducted one-way repeated-measures

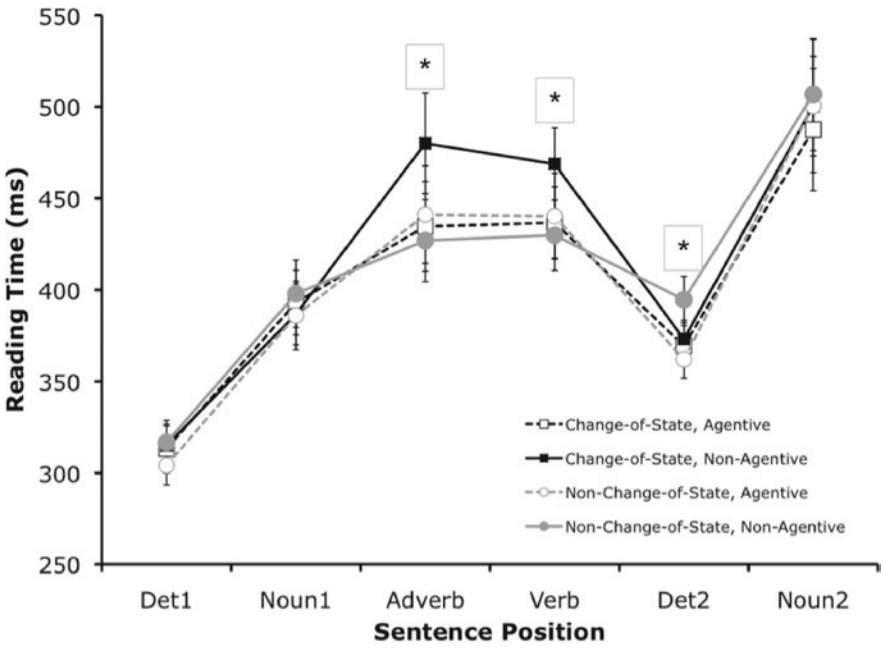

Fig. 1: Reading times (RT) for each segment of the four sentence types. Asterisks represent significant main effect of sentence type at sentence position.

ANOVAs and pairwise analyses (Fischer's PLSD with Bonferroni correction) at the Adverb, Verb, and at the two complement Noun Phrase positions, Determiner and Noun. All results were corrected for violations of sphericity using the Greenhouse-Geisser correction. At the **Adverb** position, there was a main effect of sentence type, again in the subjects analysis only, $F1$ (36, 108) = 7.76, $p < .0001$, $F2$ (15, 540) = 1.90, $p = .13$. In pairwise (Bonferroni-corrected) analyses, the [+CS, −AG] condition was significantly slower than the three other conditions in the subjects analyses (all p's < .01), and slower only than the [−CS, −AG] condition in the items analysis ($p < .05$). No other comparisons at the Adverb position resulted significant. At the **Verb** position, there was a similar pattern of results: there was a main effect of sentence type in the subjects analysis, $F1$ (3, 108) = 3.99, $p = .01$, $F2$ (3, 93) = 1.83, $p = .15$. And in pairwise comparisons, the [+CS, −AG] condition was also significantly slower than the other three conditions in the subjects analyses (all p's < .05), and slower than the [−CS, −AG] condition ($p < .05$) in the items analysis. No other comparisons were statistically significant at the Verb position. At the complement **Determiner** position (Det2), there was a significant main effect of sentence type, $F1$ (3, 108) = 7.98, $p < .0001$, $F2$ (3, 93) = 3.97, $p = .01$. The pairwise comparisons between the different sentence types at the Determiner position produced a pattern of results different from the Adverb and Verb positions. The [−CS, −AG] was significantly slower than the other conditions in both subjects (all p's < .01) and items analyses (all p's < .05). At the **Noun** complement position, there was no main effect of sentence type.

The difference between the [+CS, −AG] sentence type and the three other sentence types could in principle be attributed to the effect that the adverb itself has in sentence interpretation. That is, the adverbs used in the [+CS, −AG] condition seem to have cancelled the "volitional" feature of a prototypical Agent, presumably carried by the first NP in the subject position. The same effect was only obtained for the other non-*Agent* sentence type [−CS, −AG] after the processor encountered the *psych* verb employed in the sentences, suggesting that in these sentences agentivity was not affected by the adverb, but by the very nature of the verb. In fact, the results we obtained for the [−CS, −AG] condition at the Det2 position suggest that canonical agentivity for this condition is ruled-out only after the verb. Taken together the results for the two [−AG] conditions suggest a different pattern of interpretation, with early effect of the adverb on canonical agentivity for the [+CS, −AG] condition, and late, possibly thematic reanalysis of the role of the first NP for the [−CS, −AG] condition. However, this interpretation should be taken with caution, given the properties of the adverbs used in the different conditions. Specifically, of the 29 adverbs analyzed in the [+CS, −AG] condition, 21 (72%) contain an explicit negative prefix (such as *un-*), compared to 4 (13%) in the [−CS, −AG] condition. This raises the possibility that the "early" adverb effect

for [+CS, −AG] might be due to morphological complexity of the items used for that condition.

In order to further examine the potential effect of morphological complexity in the reading times for the [+CS, −AG] conditions compared to the other three sentence types, we ran an ANOVA on RT by condition using morphological complexity (conceived here simply as number of overt morphemes) and frequency as covariates. For these analyses we used the SUBTLEXus database (http://subtlexus.lexique.org/) for it has been shown to be a better predictor of RTs than other frequency counts (Brysbaert and New 2009). The effect of morphological complexity was significant, $F2$ (1, 97) = 15.04, p = .0002, but frequency was not. It is important to note that we did not obtain an effect of sentence type in the items analyses performed at the Adverb position, so the effect of morphological complexity simply suggests that number of morphemes has an overall effect on reading times across conditions. Pairwise comparisons between the four conditions shows that the adverbs used in the [+CS, −AG] sentence type have significantly more morphemes than the other types (all p's < .001), suggesting that our effects might be in large part attributable to this variable. However, this cannot be the only explanation for the longer RTs for the [+CS, −AG] condition at the Adverb position because an effect of morphological complexity is also found in the contrast between the adverbs employed in the [−CS, +AG] and [−CS, −AG] sentence types, although these two sentences did not differ from each other in terms of RT at the Adverb.

Overall, the results suggest that [−AG] – that is, the absence of a prototypical agent which is materialized either by the presence of an adverb or by a pure subject-*Experiencer* psych verb – yields a greater processing cost for the sentence processor. This observation will be further addressed below.

7 General discussion

The aim of the study was to investigate processing correlates of verb properties used to generate verb typologies by looking at on-line sentence processing of structures with verbs belonging to typologically different classes. To this end, a self-paced reading experiment was conducted examining the processing of verb complexity by taking into account verb internal structure (change-of-state [+CS] vs. non-change-of-state verbs [−CS]) and their thematic roles which might result in atypical or non-canonical argument realization (*Agent* [+AG] vs. non-*Agent* [−AG]). Crossing these conditions, we were able to contrast the effects of verb internal structure, A-structure, and argument realization (non-canonical) in sentence comprehension.

Two are the main findings of the study and both concern mainly [–AG] structures: A preverbal and a verbal effect of the [+CS, –AG] condition and a post-verbal effect of [–CS, –AG] sentences. At first glance, the results suggest that absence of a typical *Agent* increases complexity in sentence interpretation and yields longer RTs either in pre-verbal or post-verbal positions. Let us examine the source of this cost, leaving aside a possible adverb complexity effect, which we addressed in the previous section.

Consider a [+CS, –AG] sentence, such as *The lawyer unintentionally frightened the judge* and a [+CS +AG] sentence, such as *The lawyer skillfully persuaded the judge*. In terms of A-structure, the sentences are similar, both containing two NP arguments. However, in terms of argument realization, the *frightened* sentence violates canonical thematic hierarchy by having *Stimulus*/*Theme* before *Experiencer*. A closer look at the data reveals that the difference between the two structures occurs already preverbally most probably an effect of the *Agent*-cancelling adverb which "delays" processing. Although this effect suggests that the processor might not take into account the role of verb-assigned thematic information – and by extension it does not bear on verb typologies proper – it is nonetheless an indication of how the sentence-comprehension mechanism functions and how sensitive it might be to prototypical characteristics of NPs realized as arguments. In other words, the suggestion is that the NP that appears in the canonical subject position might be initially taken as *Agent* regardless of the actual thematic role that the yet-to-come verb might assign to it.

Along the lines we suggest, let us examine the reading process of the *frighten* ([+CS, –AG]) sentence step-by-step. Given the incremental nature of the task, the processor computes word-by-word the subject of the clause (*the lawyer*), which is an animate entity, attributing to it the theta role of *Agent* as the first NP in the sentence. As the sentence unfolds, the processor encounters an agent-oriented adverb which cancels out volition. At this point, the processor might need to change the theta role of the first NP from *Agent/Causer* (volitional, intentional actor) to *Stimulus/Theme* (involuntary causer). This process is reflected in increased RTs, suggesting that the processor takes first NPs as defaults or proto-*Agents*. This early, pre-verbal analysis of the role of the first NP is then checked against the incoming verb. Thus, it seems that the non-canonical argument realization of the [+CS, –AG] construction causes a thematic reanalysis *à la* Bornkessel, albeit pre-verbally, as suggested by the early processing cost.[4]

4 An anonymous reviewer mentions the existence of an alternative interpretation of the adverb effect. Namely, it is suggested that the adverb effect might not be an agency cancelling effect but rather an anticipation effect given the high number of *un*-adverbs in the [+CS, –AG] condition. According to the literature on anticipation in sentence processing (for a review see Kamide 2008)

The second type of construction that yielded increased RTs was the [–CS, –AG], which produced an effect most likely due to the verb. We have two main reasons for attributing the significant RTs to verb effects. First, there are no lexical differences at the Det2 position as there are at the Verb and Adverb positions, suggesting that increased times at the determiner for [–CS, –AG] sentences are likely spill-over effects from the verb. Second, it is only by processing the verb that proper thematic assignment – and thus conflict with the "default" *Agent* role assigned to the first NP – needs to be revised. It appears, thus, that once again it is the absence of the *Agent* that makes the difference. For instance, compare the [–CS, +AG] sentence *The lawyer intentionally opposed the judge* to the [–CS, –AG] sentence *The lawyer deeply disliked the judge*. Both verbs (*oppose*, *dislike*) assign two arguments which differ in terms of their thematic roles. More importantly regarding the first NP argument, *oppose* assigns *Agent*, resulting in a canonical argument realization, and *dislike* assigns *Experiencer*, resulting in an atypical argument realization. When the processor encounters a *psych* verb, it needs to re-assign thematic role to the first NP which is by default interpreted as (proto-) *Agent*. The difference with [–CS, –AG] structures is that here we do not have any "surprise effect" as in the processing of [+CS, –AG] where the processor abruptly had to reassign thematic role to NP1. What might happen instead, is a clear spill-over effect from processing the psych verb. The nature of self-paced reading task forces the participant to maintain previously seen words in memory, and prevents him/her from previewing words to the right of the word currently being processed. That is, it is possible for a region to be swamped by processing (in our case Det2), continuing from the immediately preceding region (in our case the verb). Since this preceding region (verb) is the one that differs across conditions, any significant difference observed at the following region could only be a function of the preceding region's processing difficulty. This is reflected in increased RTs and we take this to be a sign of thematic reanalysis, signaling the processor's sensitivity to semantic information such as the "ideal Proto-Agent".

From a wider perspective, the present study allows us to support the idea of "incremental interpretation" where verb-specific information is immediately accessed and integrated with ongoing processes of syntactic parsing and interpretation even before the processor encounters the verb. Moreover, we did have clear

predictability effects yield shorter RTs for the "predictee". If there was a predictability issue in our data, then the *un*-adverb would function as a predictor and this would result to shorter RTs in the verb position. However, the actual data point towards the opposite direction, that is, to significantly longer RTs for the verb after the *un*-adverb compared to RTs yielded by verbs in all other conditions. Thus, any predictability effects do not appear to be relevant for the interpretation of the data.

support for *role prototypicality* (as described within the eADM) in thematic role assignment and its effect in sentence interpretation. Thus, we see the *structural and thematic* properties of a verb playing the primary roles in sentence comprehension. Different verb classes project different hierarchical thematic structures and affect processing in distinct ways. The present experiment indicates that this verb-class specific information is not used to establish hierarchical relations between arguments, but rather appears to firstly influence processing once the argument-to-argument relation has already been built up. We suggest that the types of arguments required by a verb and their possible thematic roles are taken into account during early stages of processing.

Finally, when it comes to verb typologies, the study is a first attempt to provide behavioral (psycholinguistic) evidence regarding possible processing correlates of verb features used to generate verb typologies. Although the outcome of the study cannot be exclusively interpreted as showing a clear verb effect stemming from the absence of an Agent, our results still highlight the importance of argument structure and argument realization pointing towards its precedence over internal structure in sentential context. This finding could be interpreted as in favor of verb classifications based on argument structure properties, taking into account the nature of the self-paced reading task. In conclusion, we believe that experiments of the sort described in the present paper are a useful source of insight into the psychological reality of verb features which are used to generate verb typologies. However, further investigation using a variety of methodologies is required to enhance the promising and insightful results of the present study.

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Appendix

Sentences used in the four conditions in the experiment: change-of-state agentive ([+CS, +AG]), change-of-state non-AGentive ([+CS, –AG]), non-change-of-state agentive ([–CS, +AG]) and non-change-of-state non-Agentive ([–CS, –AG]). Sentences marked with an asterisk were not included in the analyses due to errors in the experiment script files.

[+CS, +AG] sentences

1 The alien cautiously froze the astronaut
2 The athlete ruthlessly murdered the model
3 The choreographer carefully positioned the dancer
4 The coach quickly dried the swimmer
5 The developer intentionally destroyed the city
6 The doctor resolutely healed the patient
7 The elephant purposefully crushed the ant
8 The farmer purposefully sheared the sheep
9 The FBI secretly transported the suspect *
10 The hunter maliciously killed the bear
11 The jockey successfully tamed the horse
12 The lawyer skillfully persuaded the judge *
13 The lifeguard playfully soaked the children
14 The mayor skillfully fooled the electorate *
15 The officer angrily deported the tourist
16 The police decisively stopped the gangster
17 The president deliberately hung the opponents
18 The principal determinedly evacuated the students *
19 The prisoner cunningly tricked the guard
20 The queen happily knighted the musician
21 The rancher cruelly branded the calf
22 The scientist quietly assembled the robot

23 The soldier cruelly assassinated the president *
24 The troops viciously flooded the village
25 The trucker cruelly squished the squirrel
26 The vet carefully cleaned the rabbit
27 The volunteer cautiously inoculated the refugee *
28 The vulture eagerly smashed the crab
29 The whale ravenously devoured the sea lion
30 The wife angrily tripped her husband
31 The witch cunningly captured the teen
32 The wizard purposefully burned the elf

[+CS, –AG] sentences

1 The alien accidentally confused the astronaut
2 The athlete unintentionally irritated the model
3 The choreographer unknowingly impressed the dancer
4 The coach inadvertently offended the swimmer
5 The developer accidentally worried the city
6 The doctor unknowingly upset the patient
7 The elephant unwittingly startled the ant
8 The farmer unwittingly aroused the sheep
9 The FBI involuntarily angered the suspect
10 The hunter unintentionally frightened the bear
11 The jockey accidentally spooked the horse
12 The lawyer unintentionally angered the judge
13 The lifeguard unknowingly delighted the children
14 The mayor accidentally irritated the electorate *
15 The officer unconsciously frustrated the tourist
16 The police unconsciously terrified the gangster
17 The president ignorantly infuriated the opponents
18 The principal unintentionally discouraged the student
19 The prisoner unknowingly charmed the guard
20 The queen accidentally upset the musician *
21 The rancher unintentionally awoke the calf
22 The scientist unknowingly inflamed the robot
23 The soldier ignorantly baffled the president
24 The troops mistakenly surprised the village *
25 The trucker accidentally scared the squirrel
26 The vet accidentally annoyed the rabbit
27 The volunteer ignorantly perplexed the refugee
28 The vulture inadvertently terrified the crab

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29 The whale unknowingly horrified the sea lion
30 The wife unconsciously calmed her husband
31 The witch involuntarily alarmed the teen
32 The wizard unintentionally tricked the elf

[–CS, +AG] sentences

1 The alien forcefully shoved the astronaut
2 The athlete brazenly ridiculed the model
3 The choreographer intentionally poked the dancer
4 The coach firmly held the swimmer
5 The developer skillfully circled the city *
6 The doctor viciously bullied the patient
7 The elephant enthusiastically raced the ant
8 The farmer maliciously pulled the sheep
9 The FBI skillfully located the suspect *
10 The hunter persistently followed the bear
11 The jockey happily patted the horse
12 The lawyer intentionally opposed the judge
13 The lifeguard intently watched the children
14 The mayor unsuccessfully manipulated the electorate
15 The officer angrily interrogated the tourist
16 The police viciously tortured the gangster *
17 The president maliciously slandered the opponents
18 The principal sternly whipped the student
19 The prisoner brazenly slapped the guard
20 The queen carefully tapped the musician
21 The rancher purposefully dragged the calf
22 The scientist determinedly advertised the robot *
23 The soldier deliberately hit the president
24 The troops deliberately avoided the village
25 The trucker carefully avoided the squirrel
26 The vet happily caressed the rabbit
27 The volunteer carefully carried the refugee
28 The vulture persistently chased the crab
29 The whale angrily thumped the sea lion
30 The wife lovingly hugged her husband
31 The witch maliciously clasped the teen
32 The wizard viciously kicked the elf

[–CS, –AG] sentences

1 The alien utterly dreaded the astronaut
2 The athlete subconsciously worshiped the model
3 The choreographer completely idolized the dancer
4 The coach clearly understood the swimmer
5 The developer really liked the city
6 The doctor deeply hated the patient
7 The elephant subconsciously feared the ant *
8 The farmer truly adored the sheep *
9 The FBI openly doubted the suspect
10 The hunter barely sensed the bear
11 The jockey sincerely appreciated the horse
12 The lawyer deeply disliked the judge
13 The lifeguard utterly despised the children
14 The mayor secretly detested the electorate
15 The officer unintentionally neglected the tourist
16 The police barely believed the gangster
17 The president unconsciously respected the opponents
18 The principal unknowingly resembled the student
19 The prisoner foolishly expected the guard
20 The queen strongly suspected the musician
21 The rancher unintentionally forgot the calf
22 The scientist bitterly resented the robot
23 The soldier hardly knew the president
24 The troops completely distrusted the village
25 The trucker truly pitied the squirrel
26 The vet hardly missed the rabbit
27 The volunteer eagerly awaited the refugee
28 The vulture clearly craved the crab
29 The whale secretly cherished the sea lion
30 The wife deeply loved her husband
31 The witch subconsciously envied the teen
32 The wizard fortunately admired the elf

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