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Task-dependent neural and behavioral effects of verb argument structure features

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ABSTRACT

Understanding which verb argument structure (VAS) features (if any) are part of verbs' lexical entries and under which conditions they are accessed provides information on the nature of lexical representations and sentence construction. We investigated neural and behavioral effects of three understudied VAS characteristics (number of subcategorization options, number of thematic options and overall number of valency frames) in lexical decision and sentence well-formedness judgment in healthy adults. VAS effects showed strong dependency on processing conditions. As reflected by behavioral performance and neural recruitment patterns, increased VAS complexity in terms of subcategorization options and thematic options had a detrimental effect on sentence processing, but facilitated lexical access to single words, possibly by providing more lexico-semantic associations and access routes (facilitation through complexity). Effects of the number of valency frames are equivocal. We suggest that VAS effects may be mediated semantically rather than by a dedicated VAS module in verbs' representations.

1. Introduction

Verbs occupy a pivotal role in sentence construction. They determine the number of arguments that appear in a sentence, their thematic roles (agent, theme, etc.), grammatical roles (subject, direct object, etc.) and grammatical class realizations (noun phrase, prepositional phrase, dependent clause, etc.). Within the lexicalist (or projectionist) framework, the *argument structure hypothesis* suggests that information on verb argument structure (VAS) is stored in the lexicon (Boland & Blodgett, 2006; Rappaport Hovav & Levin, 1998) and "projected" from there into sentence structures. VAS information automatically becomes available, i.e., is exhaustively accessed, upon activation of the verb. Alternatively, according to the constructivist approach, VAS may simply be induced from the lexical meaning of verbs, without a need for separate storage (e.g., Hale & Keyser, 2002). Such accounts predict that VAS information only plays a role when it is relevant, i.e., its activation depends on the context of verb use. Still, even within the lexicalist framework, it is a matter of debate which characteristics exactly are part of lexically stored VAS representations.

Because VAS processing plays out at the interface of grammar and lexicon, evidence on the neural correlates of VAS processing is directly relevant to current neurobiological models of language processing, such as the dorsal-ventral dual-route models proposed by Hickok and Poeppel (2004, 2007), Friederici (2011), and Bornkessel-Schlesewsky and Schlesewsky (2013). Neural bases of VAS processing can provide insights into the distribution of grammatical and lexico-semantic processes in the brain and possibly on how the interaction between the two is implemented neurally. In the present paper, we will interpret neural correlates of processing specific VAS characteristics in light of previously proposed general neurolinguistic models.

Besides the importance for general models of lexical representations and sentence construction, understanding whether or which VAS features are part of verbs' lexical entries also has clinical relevance. Due to the central role of verbs in sentence processing, many successful treatments of sentence production and comprehension in agrammatic aphasia are centered around verbs, training the ability to access VAS information and/or map it onto syntactic structures (Bazzini et al., 2012; Marshall, 1995; Rochon, Laird, Bose, & Scofield, 2005; Thompson, Riley, Den Ouden, Meltzer-Asscher, & Lukic, 2013). Such verb-based treatments can be further informed by VAS research in several ways. First, approaches that sequence treated stimuli in the order of increasing (Bazzini et al., 2012) or decreasing (Thompson et al., 2013)

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complexity will benefit from evidence on which VAS characteristics affect processing complexity. Then, evidence on VAS effects under various processing conditions can inform the choice of most efficient tasks to tap into VAS retrieval. It can suggest whether tasks need to be focused on syntactic structure (Thompson et al., 2013), or verb semantics (Edmonds, Nadeau & Kiran, 2009), or whether retrieval of isolated verbs may provide sufficient exposure to VAS. Lastly, research on the neural bases of VAS processing may suggest targets for brain stimulation treatments of verb and/or sentence processing in aphasia (Cappa, Sandrini, Rossini, Sosta, & Miniussi, 2002; Fertonani, Rosini, Cotelli, Rossini, & Miniussi, 2008; Marangolo et al., 2013), as well as inform pre-surgical language mapping, where verb tasks seem more promising than noun tasks (Havas et al., 2015).

So far, most studies on VAS have focused on effects of the verb's valency (number of arguments), whereas data on other VAS characteristics and, importantly, on how VAS access is modulated by processing conditions, are limited. The current study used functional neuroimaging and behavioral experiments to assess the processing load associated with three VAS features that have hitherto been relatively understudied: the number of subcategorization options, number of thematic-role options and number of valency frames. Below, we outline previous evidence on neural and behavioral effects of individual VAS characteristics in healthy speakers and show that most effects are still inconclusive and need more research in light of processing conditions.

1.1. Valency

The verb's valency refers to the number of arguments that are used with the verb in a sentence and represent participants of the corresponding action. For example, intransitive verbs have only one argument (*Jack laughs*), transitive verbs have two arguments (*Jack calls Anna*), and ditransitive verbs have three arguments (*Jack gives Anna a present*). Verbs with higher valency (i.e., greater number of arguments) typically impose a greater processing cost, as demonstrated in both single-word-level tasks (e.g., naming: Malyutina & Den Ouden, 2015) and sentence-processing tasks (e.g., cross-modal lexical decision interference: Ahrens & Swinney, 1995; Shapiro, Brookins, Gordon, & Nagel, 1991). However, other studies show behavioral facilitatory or null effects of increased valency (Assadollahi, Meinzer, Flaisch, Obleser, & Rockstroh, 2009; Malyutina & Den Ouden, 2015; Rodriguez-Ferreiro, Llorenc, & Sanz-Torrent, 2014; Thompson, Bonakdarpour, & Fix, 2010; Thompson et al., 2007). It is noteworthy that such studies have generally employed shallow processing tasks, such as lexical decision. Such tasks may not require exhaustive access to all VAS components, in contrast with tasks that induce deeper processing.

In neuroimaging studies, the processing of verbs with higher valency, even in single-word tasks, is typically associated with increased neural activation in a network of left temporal and parietal regions, such as posterior temporal, angular and supramarginal gyri (Den Ouden, Fix, Parrish, & Thompson, 2009; Meltzer-Asscher, Mack, Barbieri, & Thompson, 2015; Thompson et al., 2007; Thompson et al., 2010), rather than exclusively with areas traditionally associated with syntactic processing, such as Broca's area. However, Hernandez, Fairhall, Lenci, Baroni, and Caramazza (2014) used a lexical decision task and found an effect in the opposite direction: stronger frontal and temporal activation for intransitive than transitive verbs, possibly due to greater prototypicality of transitive predicates and general task-specificity of valency effects.

Overall, both neuroimaging and behavioral findings suggest that valency information is stored as part of the verb's lexical entry. It is accessed exhaustively upon lexical activation even under conditions when no sentence context drives direct activation of all arguments. Task-dependent patterns suggest that the effect of valency may be modulated by processing conditions.

1.2. Subcategorization options

The verb's subcategorization options are the possible morphosyntactic realizations of its arguments. For example, some transitive verbs only attach noun phrases as their second argument (*He completed the work* / ∗*He completed that*...), whereas others may be complemented by either noun phrases or dependent clauses (*He forgot the poem* / *He forgot that he had an appointment*). Early behavioral work demonstrated that verbs allowing a greater number of subcategorization options come at a greater processing cost, even when used in the same type of syntactic structure as verbs with a lower number of subcategorization options (in paraphrasing and anagram solution tasks: Fodor, Garrett, & Bever, 1968; rapid visual presentation comprehension: Holmes & Forster, 1970; time-compressed speech comprehension: Chodorow, 1979). However, later experiments did not replicate this effect (secondary task during sentence processing: Shapiro, Zurif, & Grimshaw, 1987; lexical decision and word-class judgment: Rodriguez-Ferreiro et al., 2014).

In neuroimaging research, Shetreet, Palti, Friedmann, and Hadar (2007) found that processing sentences that contain verbs with a greater number of subcategorization options was associated with increased activation in the left superior temporal gyrus and inferior frontal cortex (BA 9, 47). In Shetreet, Friedmann, and Hadar (2010), processing of subcategorization options (or, in their terminology, 'complementation frames') was also associated with the left superior temporal gyrus.

Overall, most previous research indicates that subcategorization options are exhaustively accessed in verb processing. However, most evidence comes from sentence-level tasks and it is of interest whether the effect holds in single-word processing.

1.3. Number of thematic options

VAS may also entail information on thematic roles of the verb's arguments. For example, the argument of the intransitive verb '*to break*' has the thematic role of *patient* (i.e., a "passive" participant that the action is happening to; *The glass broke*), whereas the argument of the intransitive verb '*to run*' has the thematic role of *agent* (i.e., an active participant executing the action; *The boy is running*). The thematic role of patient is less common or "canonical" for the subject position than the thematic role of agent and possibly involves syntactic movement of the verb argument from its original object position (where it is generated as the complement of the verb) to the subject (specifier) position in the syntactic structure (Levin & Rappaport-Hovav, 1994).

A lexical-decision fMRI study by Meltzer-Asscher, Schuchard, Den Ouden, and Thompson (2013) addressed thematic roles by contrasting alternating-transitivity verbs (e.g., '*to break*', '*to boil*') with non-alternating unergative verbs (e.g., '*to run*'). Alternating verbs were associated with increased activation in bilateral angular and supramarginal gyri, middle and superior temporal and middle and superior frontal gyri. However, the experimental design did not tease apart whether the effect was indeed due to the more complex (non-canonical) thematic role assignment by alternating verbs, or to the greater number of valency frames of alternating verbs (see Section 1.4). Meltzer-Asscher et al. (2015) contrasted unaccusative verbs to non-alternating transitive and unergative verbs in lexical decision and found that thematic role complexity (non-canonicity) was associated with greater activation in the left precentral and inferior frontal gyri. More research is warranted to isolate the effects of the number of thematic options and valency frames.