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Sit down and read on: Working memory and long-term memory in particle-verb processing

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We dedicate this article to Robert Schreuder, who unfortunately did not live to see its realisation.

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ABSTRACT

Particle verbs (e.g., *look up*) are lexical items for which particle and verb share a single lexical entry. Using event-related brain potentials, we examined working memory and long-term memory involvement in particle-verb processing. Dutch participants read sentences with head verbs that allow zero, two, or more than five particles to occur downstream. Additionally, sentences were presented for which the encountered particle was semantically plausible, semantically implausible, or forming a non-existing particle verb. An anterior negativity was observed at the verbs that potentially allow for a particle downstream relative to verbs that do not, possibly indexing storage of the verb until the dependency with its particle can be closed. Moreover, a graded N400 was found at the particle (smallest amplitude for plausible particles and largest for particles forming non-existing particle verbs), suggesting that lexical access to a shared lexical entry occurred at two separate time points.

1. Introduction

Whenever we encounter a word in a sentence, we retrieve its meaning and morphosyntactic information from long-term memory (i.e., the mental lexicon; Ullman, 2001). While most lexical entries correspond to a single word each in the syntactic structure, verbal compounds (e.g., *look up*), which are stored as single lexical entries (Cappelle, Shtyrov, & Pulvermüller, 2010; Jackendoff, 2002), are expressed by multiple words in the syntactic structure (McIntyre, 2007). We follow the literature by using the term "particle verbs" to refer to these constructions.

In Dutch, particle verbs consist of a head verb and a particle, which can be a preposition or an adverb. In a sentence, other lexical units can separate a verb and its particle (Booij, 1990). An example is given in (1), with the head verb and the particle indicated in subscript:

(1)	De	bank	*spiegelt*$_{(V)}$	haar	nieuwste	klanten	hoge	winsten	*voor*$_{(P)}$
	The	*bank*	mirrors$_{(V)}$	*her*	*newest*	*customers*	*high*	*profit*	before$_{(P)}$

'The bank promises high profits to its latest customers'

In (1), the verb (V) and its particle (P) form a non-adjacent dependency: Particle processing requires prior verb processing, such that the verb's syntactic and semantic properties can be assigned to the particle (Hawkins, 1999, 2004). Conversely, the verb of a sentence involving a particle verb can only be interpreted once its particle has been encountered: In (1), the idiomatic meaning 'promises' can only be accessed after recognising the particle *voor*,

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six words downstream from its verb. In (1), particle-verb recognition involves both a primary and a secondary lexical access. In addition to this lexical dependency, verb-particle dependencies may have a syntactic dimension (Hoekstra, 1988; Hoekstra, Lansu, & Westerduin, 1987), involving the upstream verb and its stranded particle (Booij, 2002). In addition to their dual nature, particle-verb dependencies are different from purely syntactic dependencies (e.g., relative pronouns, topicalisation, wh-movement) in that most particle verbs can also appear without a particle, resulting in an uncertain dependency.

While their dual nature and uncertainty differentiate verb-particle dependencies from other dependencies, verb-particle dependencies share their working-memory reliance with other types of syntactic dependencies. As exemplified in (1), any number of words can intervene between the verb and the particle; thus, the first dependent (i.e., the verb) must be held in working memory until the second dependent (i.e., the particle) is encountered. While previous EEG research has associated frontal negative ERP components with the working-memory storage of syntactically dependent elements (relative pronouns: King & Kutas, 1995; Ueno & Garnsey, 2008; topicalisation: Felser, Clahsen, & Münte, 2003; wh-movement constructions: Fiebach, Schlesewsky, & Friederici, 2002; Kluender & Kutas, 1993; Phillips, Kazanina, & Abada, 2005), only few studies have experimentally approached the comprehension of particle verbs in sentence context (Frazier, Flores d'Arcais, & Coolen, 1993; Smolka, Komlósi, & Rösler, 2009; Zwitserlood, Bolwiender, & Drews, 2004; for production, see Konopka & Bock, 2008) and even fewer have done so using techniques with high temporal resolution, such as ERPs (Cappelle et al., 2010; Isel, Alter, & Friederici, 2005). As a result, existing psycholinguistic models of particle-verb processing are incomplete (e.g., Hillert & Ackerman, 2002; Schreuder, 1990).

The present study aimed at examining the involvement of working memory (dependency formation) and long-term memory (mental-lexicon access) in the processing of particle-verb dependencies. We carried out an experiment with Dutch participants who read sentences while their electroencephalogram (EEG) was recorded. Two research questions were addressed, described separately below, with independent sets of sentences used to test effects respectively at the upstream verb and sentence object, and at the downstream particle.

1.1. Syntactic dependencies and working memory

The first research question addressed whether the language system exhibits early sensitivity to the possibility that an upstream verb is followed by a downstream particle. As mentioned above, the verb and the particle syntactically depend on each other, which means that the first dependent (i.e., the verb) must be held in working memory until the second dependent (i.e., the particle) is encountered, increasing the working-memory demand. However, these dependencies are often uncertain, that is, the verb may occur without a downstream particle. So in the case of uncertain dependencies, two scenarios are possible: First, the upstream verb might be processed like any other verb, and the presence of a particle verb would only be diagnosed upon encountering the particle. Since many particle verbs can also occur without particles, it might be uneconomical to pre-allocate working-memory resources early in the sentence for the potential occurrence of a downstream particle (Gibson, 1998; Isel et al., 2005). Alternatively, the presence of a particle verb might be postulated already at the verb, resulting in the pre-allocation of working-memory resources for verbs that are potentially followed by their particle.

To investigate this question, ERPs to sentences with verbs that occur both with and without a particle in Dutch were compared with the ERPs to sentences with verbs that only occur without a particle. Left anterior negativities (LANs) have previously been associated with the maintenance of lexical items active in working memory for later integration (for review, see Kutas, van Petten, & Kluender, 2006). If the presence of a particle verb is signalled already at the verb, a LAN is a likely ERP component to reflect the increased working-memory demands associated with processing the verb.

Furthermore, we investigated whether the number of possible particles associated with a verb influences processing already at the upstream verb. That is, if the possibility of a particle occurring later in the sentence is already taken into consideration at the verb, it could be the case that verbs that only allow for a small number of different particles would require relatively less processing effort compared to verbs that allow for a large number of different particles, due to reduced competition in lexical access (Isel et al., 2005; Magnuson, Dixon, Tanenhaus, & Aslin, 2007; Revill, Aslin, Tanenhaus, & Bavelier, 2008). In this case, the amplitude of the LAN should increase parametrically as a function of the number of possible particle verbs that can be formed with the main verb. Alternatively, if the most important information for the system at the verb is whether or not a particle is likely to follow downstream, then the system may not be sensitive to the number of possible particles, but rather to the mere possibility of a particle completion. In this case, the amplitude of the LAN should be similar regardless of the number of particles that a verb can take. To investigate this issue, we manipulated our experimental materials such that ERPs could be compared following the encounter of verbs licensing only two or three particles, at least five particles, or no particle at all.

In short, three sets of verbs were used, forming the Large set, Small set, and No particle conditions. The sentences had a fixed syntactic structure: subject, verb, object (and particle in the case of the particle-verb conditions). For example, the verb *spannen* 'to tense' can be combined with at least seven particles in Dutch, whereas *kleuren* 'to colour' can only be combined with two particles, and *negeren* 'to ignore' does not allow for any particle. The sentences were formed such that these three types of verbs and the downstream objects in the sentences could be contrasted with each other. Table 1 (upper three conditions) gives an example of the experimental sentences for this research question. More examples can be found in the Supplement.

1.2. Lexical access and long-term memory

Our second research question addressed the process of lexical access in long-term memory in particle-verb processing: Whereas a particle verb has a single entry in the mental lexicon (cf. Cappelle et al., 2010), the time frame for single word recognition (150–200 ms; Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006; Pulvermüller & et al., 2001), is too small to recognise an entire particle verb when the particle occurs downstream in the sentence. Hence, the recognition of a particle verb's lexical entry may require both a first lexical access on head-verb encounter and a second lexical access on particle encounter.

To examine lexical access in particle-verb processing, we constructed Dutch sentences involving particle verbs while varying the particle in three different ways: For a verb that allows for a particle, the downstream particle could be (a) a particle forming an *existing*, semantically interpretable particle verb, fitting the sentence context (Well-formed condition); (b) a particle that, combined with the head verb, would form an *existing* particle verb whose meaning does not fit the sentence context (Semantic violation condition); or (c) a particle that, combined with the verb, would form a *non-existing* particle verb, which has no meaning and therefore also does not fit the sentence context (Morpholexical violation condition). Thus, the sentences across the three