Do Particle Verbs Share a Representation with their Root Verbs? Evidence from Structural Priming

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Abstract

Many languages have particle verbs like *meegeven* in Dutch, in which a particle (“mee”, with) sometimes appears independently from the root verb (“geven”, give). To investigate whether particle verbs and their root verbs share a lexical-syntactic (lemma) representation, we tested whether *structural priming* (the tendency for speakers to repeat sentence structure) is boosted by lexical overlap between prime and target verbs. Priming was larger with repetition of the identical verb than with root-only repetition and larger with particle-only repetition than without lexical repetition. These findings support a dual-lemma representation for particle verbs: one lemma represents the verb-particle combination (separately from the root), another lemma represents the particle (shared with other particle verbs). Finally, priming was larger from root to particle verb than between two different particle verbs with identical roots, suggesting that particle-verb lemmas are connected to their root-verb lemmas but not to each other.

Keywords: particle verb, structural priming, lexical overlap, syntax

Introduction

When speakers construct a sentence, they need to retrieve the corresponding lexical item of each individual word from long-term memory (Jackendoff, 1995, 2002). Many psycholinguistic theories propose that each word has a separate "lemma" representation (Levelt et al., 1999), where a lemma is a lexical representation at the interface between meaning and form, which is connected to syntactic features such as word class, grammatical gender, and on some accounts even syntactic-combinatorial information (e.g., Pickering & Branigan, 1998; Schoonbaert et al., 2007). For instance, there would be separate lemmas for "ball" in its toy meaning and its dance meaning, even though both lemmas are connected to the same word form (Cutting & Ferreira, 1999).

However, less is known about the representation of phrasal words. Many languages allow particle verbs, in which a particle co-occurs with a root verb and either forms a single word with the root verb or occurs separately from the root verb, dependent on the particle and the syntactic context. For example, Dutch has the particle verb "meegeven" (give to someone going away) in which the particle "mee" (with) can be separate from its root verb "geven" (give), as in sentence (1). Particle verbs sometimes have a different meaning from the root verbs (e.g., "opgeven", give up, is unrelated to give), but sometimes the particle merely alters the sense. For instance, "mee" adds a sense of guidance in verbs like "meegeven" (as in a parent giving their child a packed lunch to take to school) or of solidarity in verbs like "mee-eten" (eat with us, join for dinner; Geerts et al., 1984).

(1) De politieman <u>geeft</u> de soldaat een hoed <u>mee</u> (The policeman gives the soldier a hat).

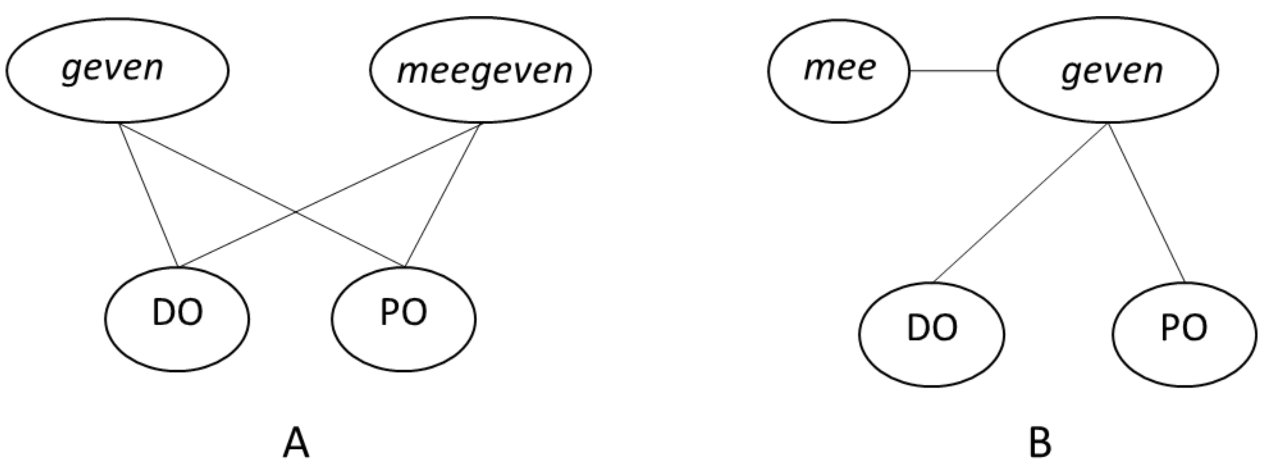
As a particle verb like "meegeven" can have a similar meaning as its root verb "geven", the question can be raised whether particle verbs share their lemma representation with their root verbs, with a connection to the particles (shared lemma account), or whether particle verbs have their own independent lemma representation (separate lemma account). In this paper, we investigate whether the linguistic representations of particle verbs are shared or separate from their root verbs during language production.

The expression with particle verbs as in (1) is common in many Germanic languages such as Dutch, German, Swedish, and English. Linguistic theories proposed several approaches to the construction of the syntactic representation of particle verbs (see Dehé et al., 2012 for a review), which map onto the shared and separate lemma accounts discussed above. According to some accounts, the root verb and the particle combine together as a complicated head presyntactically (i.e., "[V Part]", this is sometimes called the morphological approach; see Dehé, 2001; Johnson, 1991; Neeleman & Weerman, 1993). If we map this account onto psycholinguistic accounts of the lemma stratum, particle verbs (as a single word) are stored as independent representations with independent links to syntactic information, separate from the representations of their root verbs. For instance, the particle verb "meegeven" would have its own lemma representation that is connected to combinatorial syntactic information, such as the DO and PO combinatorial nodes (DO indicates Double-Object structure; PO indicates Prepositional-Object structure). This account corresponds to Model A in Figure 1, which is based on Pickering and Branigan's (1998) lexicalist residual activation model.

Other accounts assume that the root verb and the particle are two different heads that jointly form one phrasal constituent (i.e., "V'", referred to as the syntactic complex predicate approach in linguistic theories, see Booij, 1990; Dehé et al., 2012; Farrell, 2005a; Lüdeling, 2001; Zeller, 2001). In this approach, the particle verb is a phrasal construction (i.e., a combination of a verb and other word, see Booij, 2019). Mapped onto the psycholinguistic model, it can be represented by two lemmas corresponding to a two-word phrase with a syntactic connection (e.g., “mee-geven”); the combinatorial nodes are then connected to the root verb (see model B in Figure 1). It is important to note that these models only apply to particle verbs with the same valency as their root verbs. Particle verbs with a different valency from their root verbs (e.g., “opgeven (give up)” is a transitive verb and “geven (give)” is a ditransitive verb) must have separate lemmas, which are connected to different combinatorial nodes from their root verbs.

Figure 1

Two possible models for particle verb and root verb representations at the lemma level, based on Pickering and Branigan’s (1998) residual activation model



Note. Model A depicts the separate lemma account, model B depicts the shared lemma account. “meegeven” means “give” (to someone leaving), “geven” means “give”, and “mee” means “with”. The nodes for mee, geven, and meegeven represent lemmas and the nodes for DO and PO represent combinatorial information corresponding to double object and prepositional object ditransitive sentences. The link between “mee” and “geven” in model B, represents a syntactic combination between the lemma node of the verb “geven” and particle “mee”; and the links between lemma and combinatorial nodes (DO or PO) represent syntactic combinations for each verb.

In order to distinguish the separate or shared lemma account for particle verbs, we summarize the evidence from comprehension and production studies below, discuss the possibility to investigate lemma representations (separate or shared) with structural priming paradigms, and then report three structural priming experiments.

Particle Verbs in Comprehension

A perhaps superficial argument for a separate-lemma account is that dictionaries have separate entries for root verbs and particle verbs, consistent with a separate-lemma account (e.g., the Dutch dictionary *Van Dale*, 2015). For instance, the verb “meegeven” is listed in Van Dale as a separate entry. Its first meaning is “to give to someone who is leaving”. The dictionary entry also specifies that the particle sometimes attaches to its root verb, for instance in the past participle (“heeft meegegeven”, has given) and is sometimes separate, for instance in the simple past tense (“gaf mee”, lit. gave with). Because the particle can appear as a prefix of the root verb, some linguistic theories argued for a morphological derivation process for particle verbs at the word level (Cappelle, 2005; Dehé, 2001; Farrell, 2005; Neeleman & Weerman, 1993). In this case, syntactic properties of the word “meegeven” store as a single lemma in long-term memory, which will be selected in the lemma retrieval stage of language processing (Dell, 1986; Levelt, 1989; Levelt et al., 1999; Roelofs, 1996), consistent with the separate-lemma account.

Several neurophysiological studies in language comprehension provided evidence for an account assuming particle verbs are represented as a single lexical entry rather than a phrasal construction (Cappelle et al., 2010; Czypionka et al., 2019; Hanna et al., 2017; Hanna & Pulvermüller, 2018; Piai et al., 2013). Some of these studies used magnetoencephalography (MEG) to record brain activity, exploiting the earlier finding that the mismatch negativity

(MMN) responds selectively to syntactic and lexical violations. The "syntactic MMN" is a reduction of the MMN in a syntactically correct condition compared to a syntactic violation condition (Friederici et al., 1993; Isel et al., 2007). In contrast, the "lexical MMN" is an enhanced MMN effect of affixes attached to a real complex word compared to a nonword, indicating an activation of lexical storage from the memory circuits (Hanna & Pulvermüller, 2014; Leminen et al., 2013; Piai et al., 2013; Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2002).

Given the different polarity of syntactic and lexical MMN effects, Cappelle et al. (2010) asked whether particle-verb combinations are represented as phrases or lexical items. They presented listeners with three different combinations of root verb and particle: non-existing (e.g., "fall up"), existing-literal (e.g., "rise up"), and existing-figurative (e.g., "heat up") particle verbs. There was a stronger MMN with existing particle verbs (either literal or figurative) than with a non-existing particle verb, indicating a lexical MMN. This supports an account assuming a single lexical item for each particle verb rather than a phrasal construction at the syntactic level. More recently, Hanna et al. (2017) found a lexical MMN even when one word intervened between root verb and particle (e.g., "rise (…) up"). This is further evidence for a whole-form representation (i.e., a single lexical entry) for particle verbs, which maps onto two structural manifestations: a continuous form with the particle attached to the root verb (e.g., "meegeven"), and a discontinuous form with the particle separated from the root verb (e.g., "geven (…) mee").

However, other authors argued for a phrasal representation. When the particle is separate from the root verb with several words intervening (1), the discontinuous verb (e.g., "geven…mee") has properties of a two-word phrase rather than a word. Therefore, particle verbs in Dutch have been argued to be stored as a combinational representation with a syntactic link

(Booij, 1990). One argument is that the intervening words within a lexical word would violate the Lexical Integrity Hypothesis, a proposal from linguistic theory according to which words are atomic units with regard to syntactic operations (Di Sciullo & Williams, 1987). According to Booij (2012), particle verbs can develop as “constructional idioms”, where the particle is not a morpheme within the root verb, but a secondary predicate while its original meaning is still available. Therefore, particle verbs are phrasal verbs (i.e., “two-word verbs”) that are represented by two lemmas (e.g., “mee” and “geven”) rather than a single integrated lemma (e.g., “meegeven”). In this view, the particle “mee” needs its own independent lemma representation which is connected to its meaning and also links to its own grammatical information. The root verb “geven” would be represented by a shared lemma node representing both the particle verb “meegeven” and root verb “geven”, connected to the same meaning “give”.

Compared to the hypothesis of an integrated lemma representation of particle verbs separated from their root verbs, the decomposable view that particle verbs map onto two lemmas has more flexibility in both semantic and syntactic analysis, especially when considering sentences with the particles separate from their root verbs. Some evidence for this hypothesis comes from comprehension studies of idioms (e.g., “keep it under his hat”, which has the non-literal reading “didn’t tell anyone”). For example, Cacciari and Tabossi (1988) found that the literal meaning of the last word in idioms (a key area to disambiguate between the literal and idiomatic meaning of the whole phrase) was activated 300ms faster than its idiomatic meaning in a condition without idiomatic context. They therefore proposed a view according to which comprehenders activate the same lexical items in both idiomatic and literal expressions. Applying this fully decomposable view to particle verbs, whether “geven” is processed in (1) or in a similar sentence without the particle “mee”, the same lexical item of the root verb “geven” is activated (i.e., the shared-lemma account as shown in Figure 1B).

As reviewed above, comprehension studies have not converged on either a shared or separate lemma representation between particle verbs and their root verbs. Now, we turn to production studies.

Particle Verbs in Production

Consistent with studies on the comprehension of idioms, idiom production studies also provide evidence for a decomposable view of idioms (analogous to a shared-lemma account for the representation of particle verbs). For example, Cutting and Bock (1997) investigated the mental representation of idioms (e.g., “kick the bucket” or “meet the maker” with the idiomatic meaning of “die”) by considering idiom blends (e.g., “kick the maker”). They found evidence for an account in which the syntactic properties of both the idiom and its constituents are represented and activated during processing. In three experiments, participants read idiom pairs (e.g., with overlap in syntax “hit the bullseye”, syntax and figurative meaning “meet your maker”, literal meaning “punt the pail”, or no overlap “scream bloody murder”) and then recalled one of these idioms on the basis of a cue. In one experiment, semantic overlap (both literal and figurative) slowed down recall latencies. Importantly, syntactic overlap led to more idiom blends. When speakers produced intra-idiom substitution errors (e.g., “kick the rock”), these typically involved the same grammatical category of the corresponding components (e.g., “bucket”, a noun). Idiom processing thus seems to be sensitive to syntactic features of both the full idiom and its constituent words. Another experiment showed similar error rates for literal- and figurative-meaning overlap pairs, suggesting that the literal meanings of component words were activated (also see Cacciari & Tabossi, 1988). A final experiment showed a similar error rate for decomposable and non-decomposable idioms (e.g., “pop the question” vs. “kick the bucket”), suggesting the same syntactic flexibility for idioms with different decomposability.

Given the semantic activation and syntactic sensitivity of component words in idiom production, Cutting and Bock (1997) proposed a hybrid model of idiom retrieval based on an activation model of word production (Dell, 1986; Levelt, 1989). In this model, idioms are represented by a unitary node at the lexical-conceptual level but by the lemmas of the corresponding components (words) at the lexical-syntactic level. For example, “kick the bucket” has an independent lexical-conceptual representation as a whole (associated with a verb phrase), which is connected to the meaning of “die” at the conceptual level; and then links to the separate lemmas of its component words (“kick”, “the”, “bucket”) at the syntactic level. Thus, the words in an idiom share their representations with the corresponding words when they occur individually. Moreover, such representations do not depend on whether the idiom is decomposable or not. If particle verbs are represented like idiom constructions (as Booij, 2012 indeed claims), this means there is one lexical concept for the particle verb that is connected to lemmas for the particle and root verb; the root verb lemma is the same lemma that is used when the verb is used on its own (e.g., “geven” in Figure 1B).

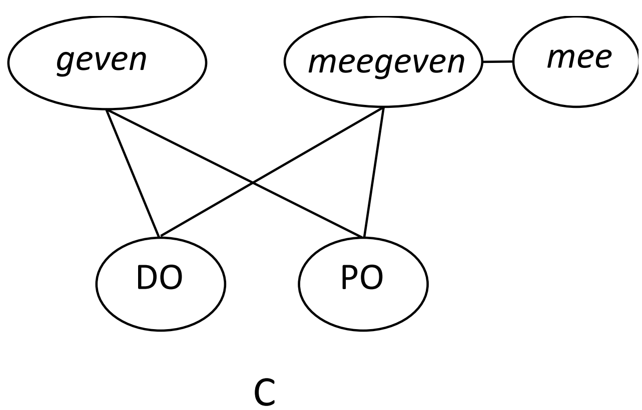
In a further study on idiom production, Sprenger et al. (2006) found that Dutch speakers produced idiomatic phrases like “trok vergeefs aan de bel” (lit. “pulled in vain at the bell”, meaning “warned without success”) more quickly when cued with a component word (e.g., “bel”, bell) than with an unrelated cue (e.g., “koek”, cake). Moreover, they were faster after a semantically (e.g., “gong”, gong) or phonologically related cue (e.g., “bed”, bed) than after an unrelated cue, suggesting the activation of the idiom’s component words. This finding is consistent with the hypothesis of the hybrid model (shared-lemma account). However, Sprenger et al. (2006) argued that the hybrid model might not work in the bottom-up processing (i.e., from lemma to concept), because the lemma nodes of component words (the "simple lemmas") cannot express the meaning of the independent node of the idiom in conceptual level. Therefore, they proposed a "super lemma" node to express the meaning relationship with the single conceptual node of the idiom. The super lemma is connected to the "simple lemmas". If we map the super-lemma account onto particle verbs, we end up with a separate-lemma account, according to which there is a separate lemma for the particle verb, which is connected to simple lemmas for the particle and root verb.

A further line of research investigated the production of single verbs (Roelofs, 1998) and supported a third account that has some commonalities with both the separate- and shared-lemma accounts (Model C in Figure 2). Specifically, following the linguistic theories that assume a syntactic complex predicate approach (Booij, 1999, 2012, 2019), Roelofs (1998) suggested that particle verbs such as "opgeven" (give up) are represented by two lemmas, one for the particle "op" and one for the verb-particle combination "opgeven". A key difference with the shared lemma account (Model B in Figure 1) is that the lemma for the particle now combines with the verb-particle combination ("opgeven") rather than the root verb ("geven"). These two lemmas are connected as a pair of lemma nodes that link to a single lexical concept (e.g., single-concept-multiple-lemma case, see Levelt et al., 1999), because the meaning of a particle verb usually cannot be interpreted by the simple combination of the meanings of its root verb and particle (e.g., Bierwisch & Schreuder, 1992). Importantly, sometimes the verb-particle construction is used as a phrase in a sentence when its root is separated from the particle like sentence (1). In this case, speakers will access the single lexical concept of "meegeven" and retrieve a pair of lemmas (i.e., meegeven-mee) from long-term memory to make them available for syntactic processing. According to this dual-lemma proposal, which is implemented in the WEAVER++

model, the lemma of the verb-particle combination is independent from the root verb, because the syntactic valency of the particle verb may differ from that of the root verb (i.e., “geven” is ditransitive and “opgeven” is transitive). Roelofs tested a number of predictions from the WEAVER++ model, in particular that speakers are faster to produce a series of words on cue if all words in the set share an initial morpheme (either a particle or a root). Indeed, participants were faster to produce the infinitive mood of particle verbs (e.g., “opgeven”) after particle-overlap prime verbs (e.g., “opzoeken”, look up) than after nonoverlap verbs (e.g., “afzoeken”, search); but there was no facilitation after a particle verb with root-verb overlap (e.g., “afgeven”, hand). In contrast, in the production of the imperative mood (e.g., “geef op”), root-verb overlap verbs (e.g., “geef af”) showed facilitation but particle-overlap verbs did not (e.g., “zoek op”). However, as the priming here occurred at the word-form level (indeed it was modulated by for instance phonological overlap), these experiments did not directly test the assumptions about particle verb representations at the lemma level.

Figure 2

An adapted lemma representation model for particle and root verbs, based on the dual-lemma hypothesis from Roelofs (1998) and Levelt et al. (1999)



Note. Model C depicts a version of the separate lemma account with two lemmas nodes for particle verbs:

one for the particle “mee” (with), and one for the verb-particle combination “meegeven” (give with). The link between “mee” and “geven”, represents a syntactic combination between the lemma node of the verb-particle combination ‘meegeven’ and the particle “mee”.

The studies reviewed above suggest that there is no consensus in the literature about the lemma representations of phrasal words and particle verbs. In comprehension research, some studies support a separate-lemma account, but others plead for a shared-lemma account. In production research, some studies converge on a shared-lemma account, whereas others plead for versions of the separate-lemma account in which there are super lemmas for particle verbs (analogous to idioms) or two separate lemmas. In the experiments reported below, we investigate the lemma representation of particle verbs by measuring a lexical repetition effect on structural priming in sentence production.

Using Structural Priming to Tap into Representations of Particle Verbs

Structural priming is a general tendency of people to reuse the specific structure of the sentence they just produced or comprehended, when they are given two alternative structures in sentence production (Pickering & Ferreira, 2008). For example, speakers tended to produce a double object (DO) structure sentence (e.g., “The rock star sold the undercover cop some cocaine”) rather than a prepositional object (PO) structure sentence (e.g., “The rock star sold some cocaine to the undercover cop”), if they were exposed to a DO structure sentence before (Bock, 1986a). Many studies have shown a robust effect of structural priming in language comprehension (Arai et al., 2007; Branigan et al., 2005; Thothathiri & Snedeker, 2008) and production (Bock, 1986a, 1986b; Bock & Loebell, 1990; Hartsuiker et al., 2008; Pickering & Branigan, 1998). Importantly, structural priming is even stronger if the prime and target have the same verb; this is called the lexical boost effect (see Bernolet et al., 2014; Carminati et al., 2019; Hartsuiker et al., 2008; Rowland et al., 2012; Scheepers et al., 2017). According to Pickering and

Branigan's (1998) account of lexical-syntactic representations, this lexical boost effect is restricted to the repetition of the syntactically licensing head (e.g., the lemma node of the verb "geven" in Figure 1). This is because there is a connection between the lemma node for the head verb and the combinatorial node; this connection would be temporarily strengthened after processing of the prime sentence. Thus, when the same verb is used again in the target sentence, more activation than usual will flow to the combinatorial node that was used in the prime. There should not be a boost from the repetition of other arguments (e.g., agent, recipient, and theme, Carminati et al., 2019; but see Scheepers et al., 2017) as these arguments are not directly connected to the combinatorial node. Additionally, the priming effect can also be boosted by semantic or phonological overlap between prime and target, but these boosts are much weaker than that of verb repetition (Bock, 1986a, 1987; Cleland & Pickering, 2003; Santesteban et al., 2010).

Important for our purposes, structural priming is an implicit method that arguably taps into linguistic representations without requiring the speakers to make explicit judgments about sentences (Branigan & Pickering, 2017). We will use this paradigm here to test the competing accounts about the representations of particle verbs at the lemma level. Earlier work using this paradigm focused on possible differences between idiomatic and non-idiomatic particle-verb combinations. For example, Konopka and Bock (2009; see Shin & Christianson, 2012 for a replication in Korean) asked participants to read sentences with two different particle verb structures (i.e., the post-verb structure "The toddler threw away one of his toys" or the post-object structure "The toddler threw one of his toys away"). The participants showed structural priming of this alternation. There was similar priming after prime conditions with idiomatic verbs (e.g., "The teenager shot off his mouth") and nonidiomatic verbs (e.g., "Judy snapped on her earrings”), suggesting that the priming effect was independent of the transparency of particle verbs, in line with the transparency-independent lexical MMN from the MEG studies (Cappelle et al., 2010; Hanna et al., 2017; Hanna & Pulvermüller, 2018; Piai et al., 2013).

These studies concerned priming of the word order of root verb (“shot”), particle (“off”), and an object NP (“his mouth”), as in “shot his mouth off” vs. “shot off his mouth”). However, they did not directly address the question of whether particle verbs share a lemma with their root verbs. It is particularly unclear whether particle verbs need an independent lemma representation when their essential meaning largely overlaps with their root verb. It is also unclear whether particle verbs need an independent lemma for their particles, that correspond to an independent phonological unit for the particle that is selected during word-form encoding. Furthermore, assuming there is an independent lemma for the particle, is this representation connected to all particle verbs using the same particle?

In this paper, we report three structural priming experiments that investigated whether Dutch speakers tend to describe target pictures with the same sentence structure (e.g., DO or PO) that they just comprehended beforehand. Importantly, there was no lexical overlap between primes and targets except for the verbs, which overlapped either fully, only in the root-verb, only in the particle, or not at all. If particle verbs share a lemma representation with their root verbs (e.g., “meegeven” and “geven” share the “geven” lemma; Figure 1B), participants should show comparable priming after identical verb primes (e.g., “geven” to “geven”) as after root-verb overlap primes (e.g., “meegeven” to “geven”), but stronger priming than after unrelated verb primes (e.g., “leveren” (deliver) to “geven”). On the contrary, if particle verbs have separate lemma representations from their root verbs (e.g., “meegeven” has a separate lemma from “geven”, Figure 1A), participants should show stronger priming after identical verb than root-verb overlap primes and unrelated verb primes. Moreover, if particle verbs are represented by one unitary lemma node with the internal particle separated from other particle verbs, participants should show comparable priming after particle overlap (e.g., “meebrengen” to “meegeven”) and unrelated verb primes (e.g., “brengen” to “meegeven”), except for possibly a small phonological boost. In contrast, if particle verbs are represented by two lemmas with a particle lemma that is shared between all particle verbs with that particle (see Figure 2), participants should show much stronger priming after the particle overlap primes than the unrelated verb primes. Experiment 1 used root-verb targets (e.g., “geven”). Experiments 2 and 3 used particle-verb targets (e.g., “meegeven”).

Experiment 1: root verb targets

Method

Participants

We recruited 90 participants (56 males and 34 females with an average age of 21), on Prolific, an online experiment platform and on Sona, a local research participation system of Ghent University. Participation was limited to students who were aged from 18 to 30 and had Dutch as their first language. Before the experiment, participants were instructed to read the consent form; they could only enter the test if they agreed with the form. Participants from Prolific were paid 7 pounds and participants from Sona were granted one course credit.

Materials

We constructed 48 experimental (for materials see https://osf.io/ven37/) and 96 filler items based on Huang et al. (2019). Each experimental item consisted of a set of six prime sentences (with two structures (DO vs. PO) and three prime verbs (Root verb vs. Particle verb vs. Different verb), see Table 1), three matching pictures (corresponding to three prime verbs, for the cover task of sentence-picture matching), and one target picture (with the same root verb as the prime, see Figure 3). In prime sentences with a particle verb, the particle always appeared at the final sentence position (note that in Dutch PO sentences, particles can also be placed before the prepositional phrase). We selected eight particle verbs and four root verbs from a corpus of Dutch written language (Colleman, 2006; Keuleers et al., 2010). Specifically, our selection criteria were that (1) target verbs needed to be transparent dative verbs, with the particle verb overlapping in meaning with the root verb (e.g., "meegeven" and "geven" have a similar core meaning of "give"); (2) both the particle verb and its root verb had to be ditransitive; and (3) the particle (e.g., "mee") needed to differ from the preposition in PO sentences (e.g., "aan", meaning "to"). We retrieved corpus data (Colleman, 2006; Keuleers et al., 2010) to calculate both structure bias (i.e., frequency of DO vs. PO sentences per verb) and lexical frequency for these verbs. Particle verbs and their root verbs showed a similar structure bias towards PO[1] (i.e., -2.14 vs. -1.70, $p>.1$). Particle verbs were less frequent than their root verbs[2] (i.e., 2.56 vs. 4.54, $p<.01$). However, a Post-Hoc regression analysis revealed that lexical frequency of prime verbs did not affect the priming effects reported below ($p>.1$).

Each prime and target picture depicted a ditransitive event involving an agent, recipient, and theme. We counterbalanced the position among items for agent and recipient (i.e., half of the items showed the agent on the left and recipient on the right; the other half had the agent on the right and recipient on the left); the theme was always in the middle. Furthermore, half of the pictures for the matching task matched with the corresponding prime sentences and half differed

[1] Structure bias was calculated as log-odds for a DO structure (i.e., log[(#DO+1)/(#PO+1)], (Jaeger & Snider, 2008). Therefore, the negative value suggested a preference of PO structure. The particle verb 'toeleveren' was not included in the corpus (Colleman, 2006), therefore it was not analyzed.

[2] Lexical frequency of particle verbs was calculated as log frequency on the raw frequency per million (i.e., log (frequency per million +1), see Keuleers et al., 2010).

with respect to one of the three entities (e.g., agent, recipient, and theme, see Cai et al., 2011; Huang et al., 2019). Underneath the prime and target picture, a verb described the action corresponding to this event. For prime pictures, three types of verb were involved: Root verbs (e.g., “geven”, to give), Particle verbs (e.g., “meegeven”, to give), and Different verbs (e.g., “leveren”, to deliver). Target pictures were accompanied by the same root verb as in the Root verb prime condition (e.g., “geven”, give). The fillers items involved 29 intransitive and 67 transitive events. Each item included one filler sentence, one picture for the sentence-picture matching task, and one filler target picture. We used 32 verbs in the fillers (18 transitive and 14 intransitive). Half of the items shared the verb between filler sentences and filler target pictures, and half did not. Similar to the counterbalanced position in experimental items, half of the agents in the filler pictures were on the left, and the other half were on right. In half of the intransitive events, the action appeared from left to right; this was reversed for the other half. Half of the pictures for the sentence-matching task matched their filler sentences and half had a different agent, theme or patient.

We constructed 6 lists of experimental items in a Latin Square design, with 48 experimental trials for each list and 8 trials for each condition. We presented all experimental trials and fillers in a pseudo-random order with the constraints that: 1) the verbs of one prime-target pair were not repeated in the next prime-target pair; 2) the first three trials were fillers; 3) each experimental trial was preceded by at least one filler trial. Participants were randomly assigned to one list.

Table1

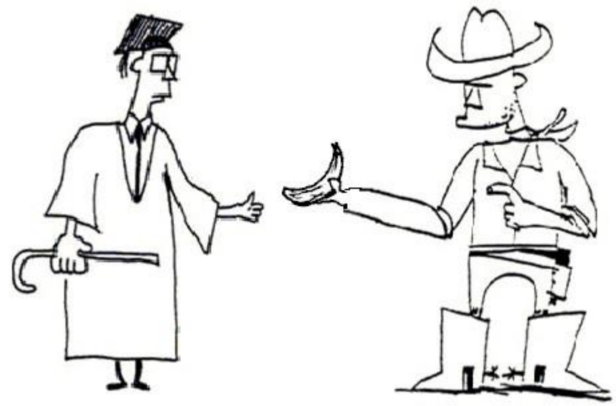
Sample stimuli in Experiment 1

Prime Condition	Example

a. DO-Root-Identical	*De politieman* ***geeft*** *de soldaat een hoed.*
	The policeman gives the soldier a hat.
b. DO-Particle	*De politieman* ***geeft*** *de soldaat een hoed* ***mee****.*
	The policeman gives the soldier a hat.
c. DO-Different	*De politieman* ***levert*** *de soldaat een hoed.*
	The policeman delivers the soldier a hat.
d. PO-Root-Identical	*De politieman* ***geeft*** *een hoed aan de soldaat.*
	The policeman gives a hat to the soldier.
e. PO-Particle	*De politieman* ***geeft*** *een hoed aan de soldaat* ***mee****.*
	The policeman gives a hat to the soldier.
f. PO-Different	*De politieman* ***levert*** *een hoed aan de soldaat.*
	The policeman delivers a hat to the soldier.

Figure 3

Example target picture in Experiment 1



GEVEN

Note. The verb underneath the picture "*GEVEN*" means "give".

Procedure

Participants completed the experiment on LimeSurvey v3.15, an online platform for experimentation. They were redirected to LimeSurvey via a link they clicked in the Prolific or Sona systems. Before the test, participants were instructed to familiarize themselves with all the entities with their names underneath the pictures. For the experimental phase, we used the comprehension-production structural priming paradigm (similar to Cai et al., 2011). Participants read a prime sentence and clicked the "Volgende" (next) button to trigger the corresponding matching picture; they were instructed to decide whether this picture matched the previous sentence by clicking the "Ja" (yes) or "Nee" (no) button. Next, they were shown a target picture accompanied by a verb, and were required to use the verb to describe the picture. They provided the response by typing the sentence in a text box below the picture. Before the experimental phase, there was a practice phase of two trials.

Scoring

We coded a response as DO-root if the target verb was followed by a noun phrase indicating the recipient and then a noun phrase indicating the theme; as PO-root if the target verb was followed by a noun phrase indicating the theme and then by a prepositional phrase (PP) including a preposition and a noun phrase indicating the recipient; as DO-particle if the target verb was followed by the recipient, the theme, and a particle; as PO-particle if the target verb was followed by the theme, a particle, and a PP with the recipient, or if the target verb was followed by the theme, a PP with the recipient, and a particle; or as 'other' responses. We excluded the DO-particle and PO-particle responses (because the verb was incorrect) and the 'other' responses from analysis, but we list their distribution in Table 2 below.

Data analysis

Table 2 shows the frequency of target responses and the priming effect for each condition. The analysis only included target responses with root verbs: DO-root responses were coded as 1, PO-root responses were coded as 0. We used Generalized Linear Mixed Models (GLMM) with the "lme4" package in R for data analysis. All analyses involved the random effect model with random intercepts and random slopes of Prime structure for subjects and items. Because a model with a full maximal random effect structure did not converge, we excluded random slopes of prime verb and the prime verb x prime structure interaction (Barr et al., 2013). We used deviation coding for two predictors: prime verb and prime structure (Scheepers et al., 2017). As for prime structure, we had one fixed predictor "Prime" indicating the main effect of structural priming. As for prime verb, we had two different coding variables indicating two contrasts among prime verb conditions with the Particle Verb condition serving as a baseline (see Table 3): Particle verb vs. Root verb (i.e., Particle vs. Root), Particle verb vs. Different verb (i.e., Particle vs. Different). In order to investigate whether repetition of prime and/or verb conditions across the experiment influences priming, we included the interaction between prime structure and trial order as a predictor into our model, and then compared it with the model that excluded this predictor. The model comparison was significant (p<.001). Therefore, we added the predictor of trial order in our data analysis. Data and scripts are available online: https://osf.io/ven37/.

Results

We excluded 11.16% of the responses. Most excluded responses (96%) were target sentences with a particle verb instead of the root verb. Table 3 shows the results of the GLMM fixed effects. The predictor of prime structure was significant (β=3.23, SE=0.17, z=19.56, p<.001), indicating a main effect of structural priming: Participants tended to reuse the structure of the previous prime sentence when they were constructing a sentence to describe the target pictures. Furthermore, the interaction between prime structure and trial order was significant (β=-0.40, SE=0.10, z=-3.97, p<.001). This finding indicated that priming decreased with increasing exposure of experimental trials throughout the experiment.

Critically, the interaction between the predictor of prime structure and the contrast of Root verb and Particle verb was significant (β=2.05, SE=0.24, z=8.71, p<.001) (see Figure 4), indicating a significant difference of priming between the Root verb and Particle verb prime conditions (i.e., 0.66 vs. 0.40, see Table 2): Participants showed more priming with root verb primes (same verb between prime and target) than with Particle verbs (same root verb, but with a particle verb in the prime). The interaction between prime structure and the contrast of Different verb and Particle verb was only marginally significant (β=-0.36, SE=0.22, z=-1.69, p=.09), showing only suggestive evidence for a stronger priming effect after primes with particle verbs than with different verbs (i.e., 0.40 vs. 0.36).

We further inspected the distribution of ‘other’ responses. Almost all of these responses were DO and PO responses, but with a particle verb rather than a root verb only. Table 2 shows that most of these incorrect productions occurred in the particle verb condition (i.e., participants repeated the prime verb in the target production, against the instructions). The number of such incorrect productions resulting in DOs and POs is large enough in the particle-verb conditions to evaluate at least numerically whether such responses show priming. Strikingly, the percentage of DO-particle responses was 83% in the DO-particle condition but only 16% in the PO-particle condition. Thus, the priming effect within this set of incorrect productions amounted to 67%, numerically similar to the priming effect we observed in the identical verb (root-verb to root-verb) condition.

Table 2

Frequency of target responses for each combination of prime verb × prime structure

Target Responses	Root verb (Identical) *geven*		Particle verb *meegeven*		Different verb *leveren*	
	DO	PO	DO	PO	DO	PO
Correct target verbs						
DO-root	592	120	363	162	467	219
PO-root	119	582	153	367	221	473
DO-root prop	0.83	0.17	0.70	0.31	0.68	0.32
Priming-DO-root	0.66		0.40		0.36	
Incorrect target verbs						

DO-particle[i]	3	1	166	31	13	8
PO-particle	3	15	34	158	17	16
DO-particle prop[ii]	0.50	0.06	0.83	0.16	0.43	0.33
Priming-DO-particle	0.44		0.67		0.10	
others	3	2	4	2	2	4

Note. Priming effect for each prime verb condition is expressed as the different proportion of DO responses (out of all DO and PO responses) between the DO and PO prime condition. Verbs in italics are example verbs for each prime condition. i) Other target responses (incorrect responses) involving Double Object sentences with particle verbs. ii) the proportion of DO-particle responses out of all DO-particle and PO-particle responses.

Table 3

Fixed effects for the linear mixed model in Experiment 1

	Estimate	*SE*	*z*	*p*
Particle vs. Root[i]	0.07	0.12	0.62	>.1
Particle vs. Different	0.06	0.11	0.55	>.1
Prime[ii]	3.23	0.17	19.56	<.001
Trial order	0.37	0.06	6.29	<.001
Trial order : Prime	-0.40	0.10	-3.97	<.001
Particle vs. Root : Prime[iii]	2.05	0.24	8.71	<.001

Particle vs. Different : Prime	-0.36	0.22	-1.69	.09

Note. The fixed factors related to prime verb represent contrasts with the particle verb (baseline) condition. i) The fixed factor of "Particle vs. Root" indicates the contrast between the root verb and particle verb conditions. ii) The fixed factor of "Prime" indicates the main effect of prime structure. iii) The fixed factor of "Particle vs. Root : Prime" indicated the difference in priming between the root verb and particle verb conditions.

Discussion

Experiment 1 demonstrated a strong structural priming effect of dative structures in the written modality in Dutch (similar to Hartsuiker et al., 2008). Participants tended to reuse the structure of the previous prime sentences when they were required to write a sentence to describe the target picture. Moreover, this priming effect decreased over trials, suggesting that the priming effect was influenced by the repeated exposure of experimental trials. It is possible that cumulative priming effects of earlier trials (Hartsuiker & Westenberg, 2000) and/or spill-over effects from the previous trial (Van de Cavey & Hartsuiker, 2016) introduced noise in the system, leading to slightly smaller priming effects across the board.

Importantly, there was much stronger structural priming when the verb in the prime sentence was identical to that in the target verb (e.g., both "geven") than when the prime verb was a particle verb with the same root (e.g., prime "meegeven", target "geven"). This supports the hypothesis that particle verbs have their own stored lexical representation that is not shared with the root verb. Furthermore, the particle verb condition (e.g., prime "meegeven", target "geven") showed slightly stronger (but only marginally significant) priming to the different verb condition (e.g., prime "leveren", target "geven"). Such a marginally significant difference should be interpreted prudentially of course. It may suggest a (weak) boost from particle verbs to their root verbs. Such a boost could result from overlap at several linguistic levels: form overlap (in the orthography, “geven” is of course contained within “meegeven”), phonological overlap (“geven” is included in “meegeven”), or semantic overlap (“to give to someone who is leaving” is semantically related to “to give”). In order to test these possibilities, we constructed a prime condition with root-verb overlap between prime and target verb (e.g., prime “doorgeven”, target “meegeven”) in Experiment 2. If this boost effect is driven by form, phonology, or semantic overlap, we expect a similar priming effect between primes with root-overlap verbs and with root verbs, because in both cases the same root is shared and both types of prime verbs have a similar meaning as their target verbs.

Analysis of the responses with incorrect target verbs revealed two interesting findings. First, there was a tendency for participants to perseverate in their lexical choice, especially in the condition with particle verb priming. Thus, after a prime sentence with “meegeven”, the target sentence often also used “meegeven”, even though the verb the participants were instructed to use was “geven”. One possibility is that the participants themselves considered “meegeven” and “geven” as instances of one and the same verb, in contrast to the separate-lemma account supported by their pattern of priming effects. The other possibility is that there is little difference for participants to include a preposition (i.e., in PO sentences) or a particle in their responses, given that some particles have the same word form as prepositions (e.g., *aan* meaning to). As a result, participants may sometimes have spontaneously changed the verb. Second, there is a numerically large structural priming effect within the (incorrect) particle-verb responses in the particle-verb conditions. This amounted to 67% and is thus similar to the priming effect observed in the root verb priming condition. Perhaps this should not be surprising, as by incorrectly repeating the verb, participants created their own repeated-verb condition.

We now turn to Experiment 2, in which the target responses will use particle verbs. If there are separate representations for particle verbs and root verbs, we expect stronger priming in the particle verb condition (e.g., "meegeven" to "meegeven") than in the root verb condition (e.g., "geven" to "meegeven").

Experiment 2: particle verb targets

We used a similar design as in Experiment 1, except that we replaced each target verb with a particle verb (e.g., "meegeven") and added a prime verb condition with root-verb overlap from the target verb (e.g., "doorgeven", pass). Therefore, we now had four prime verb conditions (see Table 4): Particle verb (identical verb), Root verb (root verb overlap), Root-overlap verb (particle verbs with root verb overlap), and Different verb (no overlap).

Table 4

Sample stimuli in Experiment 2

Prime Condition	Example
a. DO-Particle-Identical	*De politieman **geeft** de soldaat een hoed **mee**.* The policeman gives the soldier a hat.
b. DO-Root	*De politieman **geeft** de soldaat een hoed.* The policeman gives the soldier a hat.
c. DO-Root-overlap	*De politieman **geeft** de soldaat een hoed **door**.* The policeman passes the soldier a hat.
d. DO-Different	*De politieman **levert** de soldaat een hoed.* The policeman delivers the soldier a hat.

e. PO-Particle-Identical	*De politieman **geeft** een hoed aan de soldaat **mee**.*
	The policeman gives a hat to the soldier.
f. PO-Root	*De politieman **geeft** een hoed aan de soldaat.*
	The policeman gives a hat to the soldier.
g. PO-Root-overlap	*De politieman **geeft** een hoed aan de soldaat **door**.*
	The policeman passes a hat to the soldier.
h. PO-Different	*De politieman **levert** een hoed aan de soldaat.*
	The policeman delivers a hat to the soldier.

Method

Participants

We tested 160 further participants (61 males and 99 females with an average age of 22) with the same constraints on participation as Experiment 1. Participants were again recruited on the Prolific and Sona platforms. Participants from Prolific were paid 7 pounds and participants from Sona were paid 8 euros.

Materials

The items were the same as Experiment 1, except that prime and target verbs were adapted to allow the new verb type manipulations. We used 4 root verbs and 10 particle verbs in the corresponding prime and target pictures. We constructed 8 lists of experimental items in a Latin Square design. There were 48 experimental trials in each list, 6 trials for each condition.

Procedure

The procedure was the same as Experiment 1.

Scoring

We used the same scoring rules as Experiment 1, except that we added the categories DO-root-overlap and PO-root-overlap. A sentence was scored in one of these categories if it had a DO or PO structure respectively and when it used a particle verb that matched the root (but not the particle) of the target verb. We excluded the DO-root, PO-root, DO-root-overlap, PO-root-overlap, and the other responses from analysis.

Data analysis

Table 5 shows the proportion of DO responses with target particle verbs and overall DO responses by condition and also the priming effect (difference of DO proportion between DO primes and PO primes) among the four prime verb conditions. This time, the data analysis only included target responses with the target particle verbs (in other words, we again only included responses that used the verb we provided, conform instructions). The random effect structure involved random intercepts and random slopes of Prime structure for subjects and items, but no further random slopes (because of model convergence issues, Barr et al., 2013). As for the predictor of prime verb, we had three coding variables indicating three contrasts with the Root verb condition as a reference via deviation coding (Scheepers et al., 2017) (see Table 6). Again, in order to test the influence of trial order on priming, we compared a model that included the interaction between prime structure and trial order as a predictor with a model that did not. The model comparison was significant ($p<.001$). Therefore, we added the predictor of trial order in our data analysis.

Results

We excluded 5% of the responses. Most of these (88%) had a DO or PO structure but used an incorrect verb (root verb or root-overlap verb). The predictor of prime structure was significant (β=2.05, SE=0.12, z=16.44, p<.001), showing that participants tended to reproduce the structure of the prime sentences when describing the target pictures. The interaction between prime structure and trial order was significant (β=-0.35, SE=0.09, z=-3.82, p<.001), showing that priming decreased over trials. Furthermore, the interaction between prime structure and the contrast of Particle verb and Root verb was significant (β=1.98, SE=0.19, z=10.21, p<.001) (see Figure 4), indicating a similar pattern as in Experiment 1: Participants tended to produce more DO responses after DO primes with a particle verb（the same verb between prime and target) than after DO primes with the root verb (the same root verb but without a particle).

Interestingly, the interaction between prime structure and the contrast of Root-overlap verb and Root verb was significant (β=-0.39, SE=0.18, z=-2.12, p<.05), demonstrating that the priming effect with Root verb primes was stronger than with Root-overlap verb primes (i.e., 0.24 vs. 0.19, see Table 5), even though these two prime verbs had the same root verb (e.g., “geven”), had similar semantics, and overlapped in phonology and form with the target verb. Additionally, the interaction between prime structure and the contrast of Different verb and Root verb was significant too (β=-0.64, SE=0.18, z=-3.50, p<.001), demonstrating stronger priming in the Root verb than Different verb condition (e.g., 0.24 vs. 0.15, see Table 5).

Table 5

Frequency of target responses by condition and priming effect for each condition of prime verb

Target Responses	Particle verb (Identical) *meegeven*		Root verb *geven*		Root-overlap verb *doorgeven*		Different verb *leveren*	
	DO	PO	PO	PO	DO	PO	DO	PO

Correct target verbs								
DO-particle	676	201	428	222	425	267	411	275
PO-particle	265	734	449	664	457	640	505	648
DO-particle prop	0.72	0.21	0.49	0.25	0.48	0.29	0.45	0.30
Priming-DO-particle	0.50		0.24		0.19		0.15	
Incorrect target verbs								
DO-root[i]	6	4	50	6	11	2	16	6
PO-root	6	15	16	58	10	9	10	17
DO-root prop[ii]	0.50	0.21	0.76	0.09	0.52	0.18	0.62	0.26
Priming-DO-root	0.29		0.66		0.34		0.35	
DO-root-overlap[iii]	2	0	2	2	42	7	3	3
PO-root-overlap	1	1	5	4	12	30	1	7
others	4	5	10	4	3	5	14	4

Note. verbs in italic are example verbs. i) Other target responses (incorrect responses) involving Double Object sentences with root verbs. ii) the proportion of DO-root responses out of all DO-root and PO-root responses. iii) Other target responses (incorrect responses) involving Double Object sentences with root-overlap verbs.

Table 6

Fixed effects for the linear mixed model in Experiment 2

	Estimate	*SE*	*z*	*p*
Root vs. Particle [i]	0.68	0.10	7.05	<.001
Root vs. Different	0.04	0.09	0.46	>.1
Root vs. Root-overlap	0.19	0.09	2.01	<.05
Prime[ii]	2.05	0.12	16.44	<.001
Trial order	0.49	0.10	5.08	<.001
Trial order : Prime	-0.35	0.09	-3.82	<.001
Root vs. Particle: Prime[iii]	1.98	0.19	10.21	<.001
Root vs. Different : Prime	-0.64	0.18	-3.50	<.001
Root vs. Root-overlap : Prime	-0.39	0.18	-2.12	<.05

Note. The fixed factor related to prime verb represents contrasts with the root verb (baseline) condition. i) The fixed factor of “Root vs. Particle” indicates the contrast between the Particle verb and Root verb conditions. ii) The fixed factor of “Prime” refers to a potential main effect of prime structure. iii) The fixed factor of “Root vs. Particle : Prime” indicates the difference in priming between the Particle verb and Root verb conditions.

Discussion

In Experiment 2, we again found stronger priming when the identical verb was repeated between prime and target than when only the root verb was repeated (0.50 vs. 0.24), further supporting an account assuming separate representations for the particle verb and its root verb. Additionally, we found stronger priming after root verb primes than primes with different verbs (0.24 vs. 0.15) or with root-overlap verbs (0.24 vs. 0.19, even though they both shared the root verb with the targets). These results are suggestive of a connection between particle verbs and their root verbs, but not among particle verbs with the same root.

Interestingly, the distribution of incorrect responses that used the wrong verb confirms the finding of Experiment 1 that speakers tended to persist in the lexical choice of the prime verb. Target responses with only the root verb were relatively frequent in the root verb prime condition and target responses with a root-overlap verb were relatively frequent in the Root-overlap condition. Numerically, such responses with lexical perseveration seem to show priming effects.

Both Experiments 1 and 2 clearly showed stronger priming when verbs in prime and target were identical rather than overlapped only in the root verb, consistent with the hypothesis of separate lemmas for particle verbs and their root verbs. However, how are sets of particle verbs represented that overlap in their *particle* rather than their root-verb? To test this, Experiment 3 investigated whether overlap of particles between prime and target verb influence structural priming. If particle verbs share a particle lemma, we expect stronger priming after particle-overlap primes than after unrelated primes.

Experiment 3: particle verb targets

We used a similar design as Experiment 1 but replaced each target verb with a particle verb (e.g., “meegeven”). Importantly, we replaced the root-verb condition with a particle-overlap condition involving the same particle but a different root verb from the target verb (e.g., “meebrengen”, bring with). Thus, we had three prime verb conditions (see Table 7): Particle verb (identical verb), Particle-overlap verb (particle verbs with particle overlap), and Different verb (no overlap).

Table 7

Sample stimuli in Experiment 3

Prime Condition	Example
a. DO-Particle-Identical	*De non **geeft** de dokter een taart **mee**.* The nun gives the doctor a cake.
b. DO-Particle-overlap	*De non **brengt** de dokter een taart **mee**.* The nun brings the doctor a cake.
c. DO-Different	*De non **brengt** de dokter een taart.* The nun brings the doctor a cake.
d. PO-Particle-Identical	*De non **geeft** een taart aan de dokter **mee**.* The nun gives a cake to the doctor.
e. PO-Particle-overlap	*De non **brengt** een taart voor de dokter **mee**.* The nun brings a cake to the doctor.
f. PO-Different	*De non **brengt** een taart voor de dokter.* The nun brings a cake to the doctor.

Method

Participants

We tested 90 further participants (17 males and 73 females with an average age of 19) with the same constraints on participation as Experiment 1. Participants were again recruited on the Sona platform. They were granted one course credit.

Materials

The items were the same as Experiment 1, except that prime and target verbs were adapted to allow the new verb type manipulations of particle overlap. We used four root verbs and nine particle verbs in the corresponding prime and target pictures. In the prime condition with particle-overlap verbs, we included four different particles that overlapped between prime and target verb. We constructed six lists of experimental items in a Latin Square design. There were 48 experimental trials per list and 8 trials per condition.

Procedure

The procedure was the same as in Experiment 1.

Scoring

We used the same scoring rules as Experiment 1, except that we coded a response as DO-particle-overlap or PO-particle-overlap if the particle of the particle verb in the response matched the particle (but not the root) of the target verb. We excluded DO-root, PO-root, DO-particle-overlap, PO-particle-overlap, and other responses from analysis.

Data analysis

Table 8 shows the frequency of DO responses with target particle verbs by condition and also the priming effect (difference of DO proportion between DO primes and PO primes) among the three prime verb conditions. Again, we only analyzed the target responses with the target particle verbs that we instructed to be used in the description of target pictures. Similar to Experiment 1, we had two coding variables indicating two contrasts regarding prime verb with Particle-overlap verb as a reference, using deviation coding (Scheepers et al., 2017) (see Table 9). Due to model convergence issues (Barr et al., 2013), the random effect structure involved the intercept and a slope of prime structure for both subjects and items, and slopes of the contrast of “Particle-overlap vs. Particle”, the contrast of “Particle-overlap vs. Different”, the interaction between prime structure and the contrast of "Particle-overlap vs. Different" for items. We compared a model that included the interaction between prime structure and trial order as a predictor with a model that did not. The model comparison was significant (p<.05). We therefore added the predictor of trial order in our data analysis. Because of model convergence issues (Barr et al., 2013), the slopes of the contrast of "Particle-overlap vs. Particle" and the contrast of "Particle-overlap vs. Different" for items was excluded from the previous random effect structure.

Table 8

Frequency of target responses by condition and priming effect for each condition of prime verb

Target Responses	Particle verb (Identical) *meegeven*		Particle-overlap verb *meebrengen*		Different verb *brengen*	
	DO	PO	DO	PO	DO	PO
Correct target verbs						
DO-particle	540	131	399	201	312	209
PO-particle	173	572	296	489	374	479
DO-particle prop	0.76	0.19	0.57	0.29	0.45	0.30
Priming-DO-particle	0.57		0.28		0.15	
Incorrect target verbs						
DO-root[i]	3	0	3	1	6	7

PO-root	0	11	0	9	6	7
DO-particle-overlap[ii]	1	0	11	1	3	2
PO-particle-overlap	0	3	2	10	1	5
others[iii]	3	3	9	9	18	11

Note. verbs in italic are example verbs. i) Other target responses (incorrect responses) involving Double Object sentences with the root verb of the target verb. ii) Other target responses (incorrect responses) involving Double Object sentences with a particle verb sharing the particle with the target verb. iii) Other target responses (incorrect responses) involving non-ditransitive sentences and also some ditransitive sentences with different particle but same root, different root verb (as a verb), or both different particle and root of the target verb.

Table 9

Fixed effects for the linear mixed model in Experiment 3

	Estimate	*SE*	*z*	*p*
Particle-overlap vs. Particle[i]	0.29	0.11	2.59	<.01
Particle-overlap vs. Different	-0.44	0.11	-4.12	<.001
Prime[ii]	2.55	0.16	15.71	<.001
Trial order	0.49	0.05	9.09	<.001
Trial order : Prime	-0.20	0.11	-1.89	=.06
Particle-overlap vs. Particle : Prime[iii]	2.15	0.23	9.53	<.001
Particle-overlap vs. Different : Prime	-1.02	0.26	-3.86	<.001

Note. The fixed factor related to prime verb represents contrasts with the particle-overlap verb (baseline) condition. i) The fixed factor of "Particle-overlap vs. Particle" indicates the contrast between the Particle and Particle-overlap verb conditions. ii) The fixed factor of "Prime" indicates the main effect of prime structure. iii) The fixed factor of "Particle-overlap vs. Particle : Prime" indicates the difference in priming between the Particle and Particle-overlap verb conditions.

Results

We excluded 3% of the responses. Most of them (79%) were target sentences with various incorrect verbs: the root verb, a different root but the same particle (repeating the particle-overlap verb of primes), different particle but same root, both different root and particle, or different root verb of the target verb. Again, the predictor of prime structure was significant (β=2.55, *SE*=0.16, *z*=15.71, *p*<.001), demonstrating a clear structural priming effect. The interaction between prime structure and trial order was marginally significant (β=-0.20, *SE*=0.11, *z*=-1.89, *p*=.06), suggesting once again that priming decreases over trials.

Moreover, the interaction between prime structure and the contrast of Particle verb and Particle-overlap verb was significant (β=2.15, *SE*=0.23, *z*=9.53, *p*<.001) (see Figure 4). Thus, priming was stronger with full overlap compared to overlap in the particle only, analogous to stronger priming of full overlap vs. root overlap in the previous experiments. Additionally, the interaction between prime structure and the contrast of Different verb and Particle-overlap verb was significant (β=-1.02, *SE*=0.26, *z*=-3.86, *p*<.001), demonstrating stronger priming with particle overlap as compared to no overlap (i.e., 0.28 vs. 0.15, see Table 8).

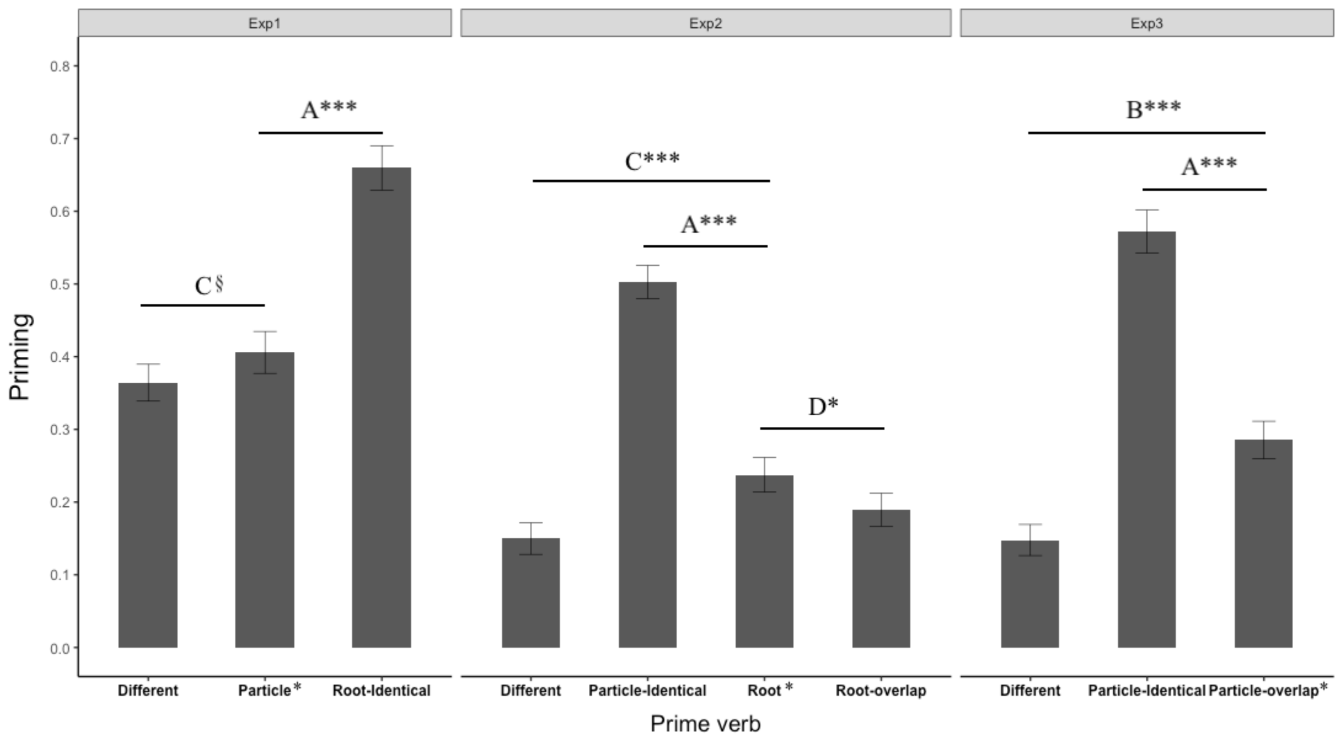
Discussion

Experiment 3 demonstrated a stronger priming effect when the verb was repeated between prime and target than when only the particle was repeated (0.57 vs. 0.28), which provides evidence for separate lemma representations for the sets of particle verbs with the same particle. Importantly, there was stronger priming after particle-overlap primes than after the no-overlap primes (0.28 vs. 0.15). There is thus a boost from particle-overlap prime verbs (e.g., "meebrengen") to the target verb (e.g., "meegeven"). This boost effect can be interpreted in terms of an account in which particle verbs are represented by two lemmas, one for the verb-particle combination and one for the particle (Roelofs, 1998), and in which the particle lemma is shared among all particle verbs with that particle.

Interestingly, the incorrect target responses used a variety of incorrect verbs. For example, 37% of all 'other' responses used the root verb of the target particle verb (e.g., '*geven*'), even though there was no prime verb condition with the root verb in this experiment; 27% used a particle-overlap verb ("meebrengen"); and 16% used a different root verb (e.g., "leveren") or a particle verb with a different particle but either the same root (e.g., "afgeven") or a different root (e.g., "afleveren"). This distribution differs from Experiments 1 and 2 where speakers tended to persist in the lexical choice of prime verb in target sentences (27% of incorrect responses repeated the prime verb in Experiment 3, compared to 88% and 96% in Experiments 1 and 2). Thus, participants were less likely to confuse the target particle verbs from the prime verbs with the same particle (e.g., "meegeven" vs. "meebrengen") than from the verbs with the same root (e.g., "meegeven" vs. "geven" or "doorgeven").

Figure 4

Priming effects in Experiments 1, 2 and 3



Note. Prime verb condition with an '*' marker in the x-axis label is the reference level for the contrasts with other conditions (e.g., Particle* in Experiment 1). Labels A indicate the comparisons of priming effect between prime verb conditions of full-overlap verb and partial-overlap verb (overlapping root verb in Experiments 1 and 2, particle in Experiment 3). Label B indicates the comparison between prime verb conditions of particle-overlap verb and different verb in Experiment 3. Labels C indicate the comparisons between prime verb conditions of partial-overlap verb (overlapping root verb) and different verb in Experiments 1 and 2. Label D indicates the comparison between prime verb conditions of root verb and root-overlap verb in Experiment 2. $^{§}p <.1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$. Error bars reflect standard errors from a by-participant analysis.

General Discussion

In three experiments, we used structural priming to investigate whether particle verbs share a lemma representation with their root verbs. We observed four main findings. First, there was *a lexical boost* in all experiments. Priming was stronger when the prime and target verb were identical, as compared to partial overlap in root (Experiments 1-2) or particle (Experiment 3) (see labels A in Figure 4). Second, there was a *particle boost*. If prime and target verb overlapped in only the particle verb (e.g., “meebrengen-meegeven”), priming was stronger compared to a particle verb target with a different verb prime (e.g., “brengen-meegeven”, see label B in Figure 4). Third, there was a *boost effect between particle verb and root verb*. Priming was stronger between particle verbs and their root verbs (and vice versa) than between different verbs and root or particle verbs (see labels C in Figure 4). Fourth, there was stronger priming between root verbs and particle verbs with that root (e.g., “geven-meegeven”) than priming between particle verbs sharing the root (e.g., “doorgeven-meegeven”, see label D in Figure 4). We now discuss these findings in turn.

We observed a lexical boost in all experiments. Specifically, Experiment 1 and 2 clearly showed stronger priming after identical verb primes than after primes that merely shared the root verb with the target (e.g., root-verb to root-verb vs. particle-verb to root-verb in Experiment 1; particle-verb to particle-verb vs. root-verb to particle-verb in Experiment 2, see labels A in Figure 4). In other words, there is stronger priming when the identical verb is repeated than when only the root is repeated. These results consistently support the predictions of the separate lemma account. That is, the particle verbs have a separate syntactic licensing head from their root verbs, with independent links to combinatorial nodes representing syntactic information like Double-Object and Prepositional-Object structure (as in model A in Figure 1 and model C in Figure 2). These findings provided direct evidence from production that particle verbs store their own representations, even when their particles are separated from their root verbs by more than one argument or word.

Second, Experiment 3 showed stronger priming after primes with particle-overlap verbs than no-overlap verbs (e.g., “meebrengen” to “meegeven” vs. “brengen” to “meegeven”, 0.28 vs.

0.15, see label B in Figure 4), indicating a boost of repeated particles. This finding suggests a particle lemma that links to the lemmas of all particle verbs containing that particle (as in model C in Figure 2). That is, particle verbs are represented by two lemmas: one for the particle (e.g., “mee”) which is shared by other particle verbs, and the other for the verb-particle combination (e.g, “meegeven”) which is separate from other particle verbs.

Third, we found a trend towards a boost of priming from particle verb to root verb in Experiment 1 (e.g., “meegeven” to “geven” vs. “leveren” to “geven”, priming effects of 0.40 vs. 0.36) and a clear boost from root verbs to particle verbs in Experiment 2 (e.g., “geven” to “meegeven” vs. “leveren” to “meegeven”, priming effects of 0.24 vs. 0.15, see labels C in Figure 4). This finding indicates a boost effect between particle verbs and their root verbs. Such a boost effect in the syntactic choice of sentence construction might be driven by overlap at several linguistic levels between particle verb and root verb: there may be a connection between root verbs and particle verbs at the lemma level and there could be repeated activation from either the semantic, phonological, or form level. We will discuss these possibilities below.

Fourth, priming from root verbs to particle verbs was also stronger than priming from root-overlap verbs to particle verbs (e.g., “geven” to “meegeven” vs. “doorgeven” to “meegeven”, 0.24 vs. 0.19, see label D in Figure 4), even though these prime conditions have the same root verb as the target and have similar semantic and phonological overlap with the target. Therefore, these differential priming effects cannot be accounted for by differences in activation from form or phonology during language production. Given that the critical root-verb meaning of these verbs (e.g., “geven (give)” is shared, the contribution of semantic differences is likely to be relatively small (see below). Rather, we assume a direct connection between particle verbs and their root verbs at the lemma level, but not among particles verb sharing the same root.

Therefore, we extend the separate lemma account with the dual-lemma hypothesis (Model C in Figure 2) to a dual lemma model with connections between particle verbs and their corresponding root verbs (see Figure 5), which we will explain below.

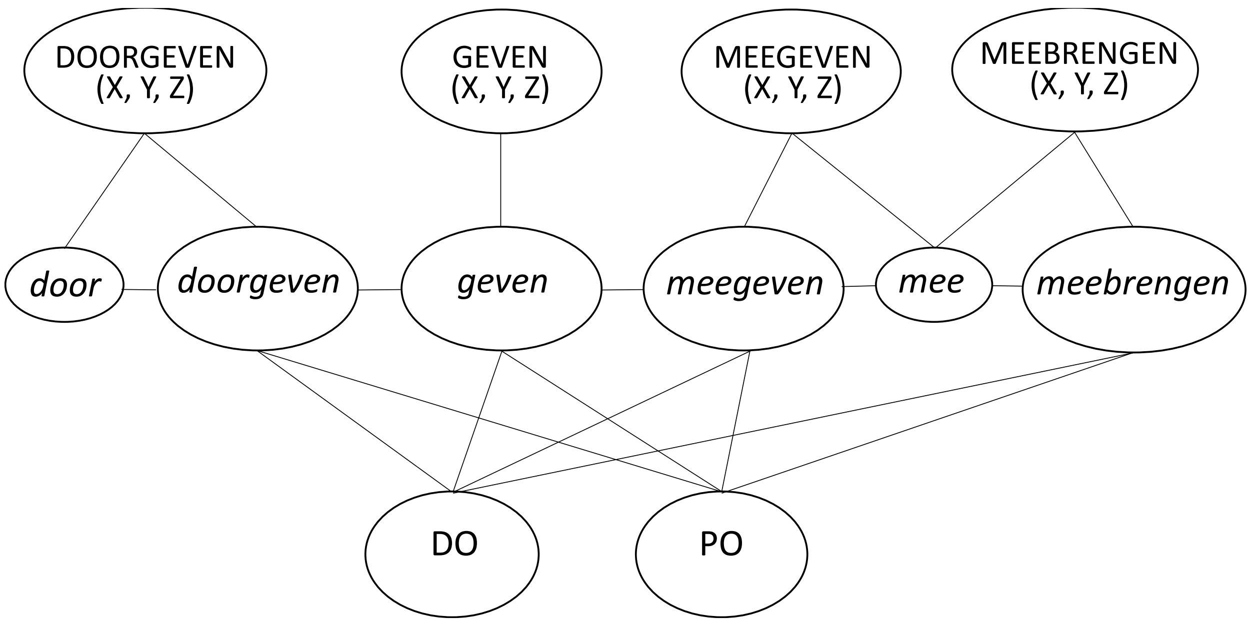
The model in Figure 5 is based on the theory of the lemma level proposed by Levelt et al. (1999) and Roelofs (1998), which has been extended to representations of combinatorial-syntactic information by Pickering and Branigan (1998). It assumes that the lemma is a syntactic representation of a lexical entry, with connections to syntactic properties. The lexical boost effects that we observed in all three experiments are clear evidence for separate lemma representations. Particle verbs are represented by one lemma node for the particle (in turn connected to its word form and to syntactic information regulating its position in the phrase) and another lemma node for the verb-particle combination, with an independent connection to syntactic combinatorial nodes. Lemma selection and lexical processing for particle verbs is similar to that of their root verbs. When the particle verb (e.g., "meegeven") is planned to be used in a specific structure (e.g., DO) in production, the corresponding pair of lemma nodes (e.g., "mee-meegeven") and syntactic combinatorial node (e.g., "DO", with a connection to the lemma node of the verb-particle combination "meegeven") will be activated.

Additionally, the boost effect between particle verbs and their root verbs and the stronger priming between root verb and particle verb than between root-overlap verb and particle verb, suggest a connection between particle verbs and their root verbs. One argument for this connection is the frequent co-occurrence and co-activation of root verbs and particle verbs during lexical access in language comprehension, especially when the particles are freestanding like *mee* (with) in sentence (1) ("De politieman geeft de soldaat een hoed mee", The policeman gives the soldier a hat). In language comprehension, the root verb "geven" is accessed before the particle verb “meegeven”, and the particle verb can only be integrated or accessed after the particle “mee” is processed at the end of the sentence. Thus, the root verb and particle verb are co-activated in comprehension. Indeed, an EEG study suggested that an (early accessed) root verb is held in working memory while the listener makes a prediction about the potential particles. Later, once the particle is encountered, the root verb and incoming particle are integrated, which triggers the access of particle verbs in long-term memory (Piai et al., 2013). The double lexical access and co-activation of particle verbs and root verbs may lead to the development of a link between these representations based on Hebbian learning, which claims that ‘units that fire together, wire together’(Munakata & Pfaffly, 2004). Similarly, Hebbian learning has been used to argue for a connection between cognate verbs (e.g., “dai-di”) in Mandarin and Cantonese (Huang et al., 2019). In sum, according to Hebbian learning accounts, speakers or comprehenders can develop a link between the co-occurring words (e.g., “geven-meegeven”, with large overlap in semantics, phonology, and orthography), based on the statistical regularities of linguistic input or output, which can help them to rapidly access the semantic information about words.

Furthermore, the particle boost effect provides evidence for a shared lemma among the particle verbs that include the same particle. On this interpretation of the particle boost effect, there is a shared particle lemma (e.g., “mee”) connected to particle verbs with the same particle (e.g., “meegeven” and “meebrengen”; see Figure 5). According to the dual-lemma account (Levelt et al., 1999; Roelofs, 1998), the particle verbs are stored in a unitary node in conceptual level, because their meaning usually cannot be interpreted by the simple combination of the meanings of their roots and particles. Then the single concept of particle verbs selects a pair of lemmas (e.g., “mee-meebrengen” for the particle verb “meebrengen”), given that particle verbs sometimes behave as phrases with the particles separating from their roots by syntactic rules. Therefore, the lemma of the shared particle between the prime and target verbs was repeatedly accessed during processing, which contributed to this particle boost effect.

Figure 5

The dual lemma model for particle verbs



Note. Each conceptual node of particle verbs (e.g., MEEGEVEN) connects to their corresponding pair of lemmas (e.g., mee-meegeven, "mee" is the lemma of the particle, "meegeven" is the lemma of the verb-particle combination). The conceptual node of the root verb (e.g., GEVEN) connects to its single lemma (e.g., geven) which is separate from but connected to the lemma of the verb-particle combination (e.g., meegeven). The lemma of the particle is shared between particle verbs that include the particle (e.g., mee). The lemmas of root verbs and verb-particle combinations connect to the combinatorial nodes of dative structures (DO or PO).

The dual lemma model we proposed here can account for most of the findings in our study. Recall that according to Pickering and Branigan's (1998) model, there is a lexical boost of priming because the lemma of the prime verb, and its connection to combinatorial nodes, is re-activated during target processing. Experiments 1 and 2 showed a lexical boost when comparing verb pairs that were identical to verb pairs sharing the root verb, but differing in (the presence of) a verb particle (e.g., “geven-geven” vs. “meegeven-geven” in Experiment 1, “meegeven-meegeven” vs. “geven-meegeven” in Experiment 2). Importantly, the connection between the particle verbs and their root verbs, explains the different priming effects when comparing the root verb (“geven”) and root-overlap particle verb (“doorgeven”) as primes for a particle verb like “meegeven”. Moreover, this connection explains the boost effect between particle verb and root verb in Experiment 1 and 2 (e.g., “meegeven-geven” vs. “leveren-geven”, “geven-meegeven” vs. “leveren-meegeven”). For instance, when the prime verb is “geven”, in the prime processing, the lemma “geven” is activated; then during target processing, the lemma pair “mee-meegeven” of the target verb “meegeven” is accessed. The lemma of the verb-particle combination “meegeven” re-activates the lemma “geven” through the link “geven-meegeven” and therefore contributes to the boost effect between particle verb and root verb. However, such a boost effect does not occur between particle verbs with root overlap (e.g., “doorgeven-meegeven” vs. “leveren-meegeven”). This is because, when the prime verb is “doorgeven”, in the prime processing, the lemma pair “door-doorgeven” is activated. Then, in the target processing of “meegeven”, the lemma pair “mee-meegeven” is selected. The selected lemmas do not re-activate the lemmas of the prime verb “doorgeven”, because there are no direct links or any shared lemmas between prime and target.

Furthermore, the shared lemma of particles between particle verbs can explain the boost effect from particle-overlap verbs to particle verbs (e.g., “meebrengen-meegeven” vs. “brengen-meegeven” in Experiment 3). When the prime verb is “meebrengen”, in the prime processing, the lemma pair “mee-meebrengen” and for instance the combinatorial node of DO are activated, and the link between “meebrengen” and “DO” is strengthened. Then in the target processing, the lemma pair “mee-meegeven” of the particle verb “meegeven” is accessed. The repeatedly activated particle lemma “mee” then re-activates the lemma of “meebrengen”, which leads to an extra flow of activation to the combinatorial node of DO (because of the strengthened link). Hence, “meebrengen” yields stronger priming than “brengen”. In sum, the critical findings of three priming experiments can best be interpreted in terms of the dual lemma model (Figure 5).

In contrast to the dual lemma model, there are two alternative hypotheses that interpret our findings as effects at the phonological or conceptual level. The phonological hypothesis suggests that the particle boost effect was driven by phonological overlap between particle verbs that shared the particles. For instance, Santesteban et al. (2010) found that structural priming of prenominal (the red bat) vs. postnominal (the bat that’s red) modification was boosted by the phonological overlap of nouns, so that priming was stronger if both prime and target nouns used a homophone like “bat” as compared to unrelated words, even without meaning overlap (i.e., a cricket bat vs. an animal bat). This finding suggests that there is phonological feedback from the word form “bat” to the lemma “bat” and then to the combinatorial node (also see Zhang et al., 2021). However, such phonological boost effect is rather weak and did not occur in other studies (e.g., there was no such boost with items like "ship-sheep" in Cleland & Pickering, 2003). Consistently, there was no phonological boost effect of structural priming in our condition with root verb overlap (e.g., “doorgeven” to “meegeven” with four phonemes overlap (“geeft [ge:ft]”, see Table 4 in Experiment 2). Therefore, the partial phonological overlap of the particle between prime and target verbs (e.g., three particles (“af”, “toe”, “mee”) with two phonemes and one particle (“terug”) with five phonemes) is unlikely to cause the particle boost effect observed in

Experiment 3. Thus, we interpreted this particle boost effect at the lemma level (see Figure 5) rather than the phonological level.

The conceptual hypothesis suggests that differences in meaning similarity among conditions of prime-target verb pairs may have contributed to our data pattern (e.g., the meaning of the verb pair “meegeven-geven” is presumably more similar than the verb pair “leveren-geven”, which might result in a semantic boost). However, we think it is unlikely that our pattern of priming effects is driven by semantic boosts of priming. First, there is little solid evidence that semantic similarity between prime and target boosts priming. Only one production study of noun-phrase structure showed a boost effect with semantic overlap of the critical head noun (e.g, “the goat that's red - the sheep that's red”, see Cleland & Pickering, 2003), but other production studies of sentence structure did not (Bock & Loebell, 1990; Carminati et al., 2008; Chen et al., 2020; Huang et al., 2016; Konopka & Bock, 2009; Messenger et al., 2012; Zhang et al., 2021). For example, the full overlap of one argument of dative sentences (i.e., agent, recipient and theme, see Carminati et al., 2019) did not boost structural priming in sentence production. Additionally, Zhang et al. (2021) found no semantic boost at all in a Mandarin alternation involving transitive sentences, even though norming data showed that the semantically related verb pairs were clearly semantically related and unrelated verb pairs were not. Second, data from a norming study (N=48)[3] of semantic similarity for all prime-target verb pairs in three experiments (excluding the identical verb condition, see Table 10 below) could not explain the full data pattern of our findings. Indeed, there is some degree of correspondence between

[3] 48 participants (24 female and 24 male; native speakers of Dutch) recruited via prolific and social media (e.g., Facebook) completed the test on LimeSurvey v3.15. They were asked to evaluate the meaning similarity of the verb pairs on a 10-point scale (i.e., “1” indicates completely different meanings and “10” indicates completely identical meanings). We had 56 experimental pairs of prime-target verbs across all three experiments. Then we constructed 56 filler pairs with 6 root verbs and 8 particle verbs that haven’t been used in our priming experiments. The items were taken from a Dutch verb corpus (Colleman, 2006).

semantic similarity and strength of priming, but this correspondence cannot explain a number of our findings. More specifically, a) there was a large difference in semantic similarity between root overlap verb pairs and control pairs in Experiment 1 (e.g., “meegeven-geven” vs. “leveren-geven”, 7.42 vs. 3.75, p<.001), but the difference in priming effect between those two conditions was small (4%) and only marginally significant; b) there was a large and significant difference in semantic similarity between root-overlap verb pairs and control pairs in Experiment 2 (e.g., “doorgeven-meegeven” vs. “leveren-meegeven”, 5.56 vs. 4.24, p<.001), but these two conditions showed a comparable priming effect (0.19 vs. 0.15).

Table 10

Semantic similarity for prime-target verb pairs in three experiments

	Prime verb	Target verb	Mean	SD
Exp1	meegeven	geven	7.42	1.08
	leveren	geven	3.75	1.69
Exp2	geven	meegeven	7.02	1.16
	doorgeven	meegeven	5.56	1.25
	leveren	meegeven	4.24	1.33
Exp3	meebrengen	meegeven	6.60	1.25
	brengen	meegeven	4.61	1.62

There were several additional findings. Interestingly, we found a lexical preservation effect in Experiment 1 and 2. That is, speakers often used the prime verb rather than the correct target verb to describe the target picture. This phenomenon is not surprising, because in Experiment 1, participants were instructed to use the target verb (e.g., “geven”) after the particle verb primes (e.g., “meegeven”) with overlap in meaning and phonology. The speakers may have sometimes been confused about whether particle verbs or root verbs are the same verb, leading to

11% target responses with incorrectly repeated prime verbs after the particle verb primes (e.g., “meegeven”). They were less confused in Experiment 2, when target verbs were particle verbs with a specific particle (e.g., “meegeven”), especially after encountering primes involving various verbs in the environment (e.g., root-overlap verb “doorgeven”, same verb “meegeven” and root verb “geven”), leading to only 2% target responses with repeated root verbs (e.g., “geven”) after the root verb primes and 1% target responses with root-overlap verbs (e.g., “doorgeven”) after root-overlap verbs primes. When we calculated the priming effect of these incorrect responses in both experiments, they both (descriptively) showed huge priming effects, which were even sometimes numerically as strong as the same verb condition in the corresponding experiment (e.g., 67% in Experiment 1). To some extent, these findings suggested a lexical boost effect with the wrong verb-repetition responses, which again supported the hypothesis of a separate lemma for the particle verb. However, this lexical preservation effect seemed to disappear in Experiment 3 with particle verbs in the target (e.g., “meegeven”), showing that participants were less confused to distinguish the particle verbs with the same particle but different root (e.g., “meebrengen”). For example, only 0.6% target responses incorrectly repeated the prime verbs after particle-overlap verbs primes. Interestingly, 1.2% target responses only used the root verbs of the target particle verbs, indicating that speakers still sometimes confused particle verbs and their root verbs, even when these root verbs were not accessed in prime processing.

The dual lemma model for particle verbs that we propose in this paper is based on the evidence from transparent verbs (e.g., “meegeven” and “doorgeven”), which not necessarily need to store an isolated representation during language processing. The case for independent representations is more obvious *a priori* for idioms, as they need to represent a separate meaning at the conceptual level, see Sprenger et al., 2006). As several comprehension studies provided evidence that lexical processing is unrelated to the transparency of particle verbs (Cappelle et al., 2010; Hanna et al., 2017; Piai et al., 2013), we expect there to be a similar representational network for opaque particle verbs (e.g., “toegeven”, “admit”) as for transparent verbs. Thus, it will be interesting for further studies to investigate this question by comparing the priming effect between opaque particle verbs and their root verbs. Note that such a comparison would still require the verbs to have the same valence. Additionally, the connection between particle verbs and their root verbs that we proposed was based on a development link with Hebbian learning. As this is an abstract learning procedure based on the statistical regularities of linguistic processing including production and comprehension, our theory predicts an independent but connected lemma representation for particle verbs and their root verbs that is used in both top-down (production) and bottom-up processing (comprehension). This cross-modalities hypothesis is also consistent with evidence from previous studies that found structural priming effects within or between comprehension and production (Bock, 1986b; Bock et al., 2007; Branigan et al., 2005; Thothathiri & Snedeker, 2008; Tooley & Bock, 2014). Thus, it will be interesting to investigate whether the dual lemma model holds for comprehension.

One potential caveat was that the constraints of particle verbs and their root verbs (i.e., consistent syntactic valency and transparency) may limit the choice of experimental materials. Given that repeated exposure of experimental trials decreased the strength of structural priming in our experiments, future studies should also consider the problem of lexical repetition in experimental design.

In sum, our findings from three structural priming experiments that directly compared particle verbs and their root verbs provided clear evidence for a separate lemma account of particle verbs during production, even though Dutch allows two intervening arguments in discontinuous constituents. We propose a separate, dual-lemma model, where particle verbs are represented by two lemmas that are independent from the root verb. There is one lemma node for the verb-particle combination, with connections to the shared root verb but not to other particle verbs. The second lemma node represents the particle, and links to all particle verbs with the same particle.

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References

Arai, M., van Gompel, R. P. G., & Scheepers, C. (2007). Priming ditransitive structures in comprehension. *Cognitive Psychology*, *54*(3), 218–250. https://doi.org/10.1016/j.cogpsych.2006.07.001

Barr, D. J., Levy, R. P., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68*(3), 255–278. https://doi.org/10.1016/j.jml.2012.11.001

Bernolet, S., Colleman, T., & Hartsuiker, R. J. (2014). The “sense boost” to dative priming: Evidence for sense-specific verb-structure links. *Journal of Memory and Language*, *76*, 113–126. https://doi.org/10.1016/j.jml.2014.06.006

Bierwisch, M., & Schreuder, R. (1992). From concepts to lexical items. *Cognition*, *42*(1–3), 23–60.

Bock, K. (1986a). Meaning, Sound, and Syntax. Lexical Priming in Sentence Production. *Journal* *of Experimental Psychology: Learning, Memory, and Cognition*, *12*(4), 575–586. https://doi.org/10.1037/0278-7393.12.4.575

Bock, K. (1986b). Syntactic persistence in language production. *Cognitive Psychology*, *18*, 355–387.

Bock, K. (1987). An effect of the accessibility of word forms on sentence structures. *Journal of Memory and Language*, *26*(2), 119–137. https://doi.org/10.1016/0749-596X(87)90120-3

Bock, K., Dell, G. S., Chang, F., & Onishi, K. H. (2007). Persistent structural priming from language comprehension to language production. *Cognition*, *104*(3), 437–458. https://doi.org/10.1016/j.cognition.2006.07.003

Bock, K., & Loebell, H. (1990). Framing sentences. *Cognition*, *35*(1), 1–39. https://doi.org/10.1016/0010-0277(90)90035-I

Booij, G. (1990). The boundary between morphology and syntax: Separable complex verbs in Dutch. *Yearbook of Morphology 3*, *3*, 45–63. https://openaccess.leidenuniv.nl/handle/1887/11169

Booij, G. (1999). *The phonology of Dutch*. Oxford University Press.

Booij, G. (2012). Separable complex verbs in Dutch: A case of periphrastic word formation. *Verb-Particle Explorations*, *August*. https://doi.org/10.1515/9783110902341.21

Booij, G. (2019). *The morphology of Dutch*. Oxford University Press.

Branigan, H. P., & Pickering, M. J. (2017). An experimental approach to linguistic representation. *Behavioral and Brain Sciences*, *40*(2017). https://doi.org/10.1017/S0140525X16002028

Branigan, H. P., Pickering, M. J., & McLean, J. F. (2005). Priming Prepositional-Phrase Attachment During Comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(3), 468–481.

Cacciari, C., & Tabossi, P. (1988). The comprehension of idioms. *Journal of Memory and Language*, *27*(6), 668–683. https://doi.org/10.1016/0749-596X(88)90014-9

Cai, Z., Pickering, M. J., Yan, H., & Branigan, H. P. (2011). Lexical and syntactic representations in closely related languages: Evidence from Cantonese–Mandarin bilinguals. *Journal of Memory and Language*, *65*, 431–445.

Cappelle, B. (2005). Particle Patterns in English A Comprehensive Coverage. *Event (London)*.

Cappelle, B., Shtyrov, Y., & Pulvermüller, F. (2010). Heating up or cooling up the brain? MEG evidence that phrasal verbs are lexical units. *Brain and Language*, *115*(3), 189–201. https://doi.org/10.1016/j.bandl.2010.09.004

Carminati, M. N., van Gompel, Roger P. G. Scheepers, C., & Arai, M. (2008). Syntactic priming in comprehension: The role of argument order and animacy. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(5), 1098.

Carminati, M. N., van Gompel, R. P. G., & Wakeford, L. J. (2019). An investigation into the lexical boost with nonhead nouns. *Journal of Memory and Language*, *108*(July), 104031. https://doi.org/10.1016/j.jml.2019.104031

Chen, X., Branigan, H. P., Wang, S., Huang, J., & Pickering, M. J. (2020). Syntactic representation is independent of semantics in Mandarin: evidence from syntactic priming. *Language, Cognition and Neuroscience*, *35*(2), 211–220. https://doi.org/10.1080/23273798.2019.1644355

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. *Journal of Memory and Language*, *49*(2), 214–230. https://doi.org/10.1016/S0749-596X(03)00060-3

Colleman, T. (2006). *De Nederlandse datiefalternantie: een constructioneel en corpusgebaseerd* *onderzoek*. Ghent University.

Cutting, J. C., & Bock, K. (1997). That's the way the cookie bounces: Syntactic and semantic components of experimentally elicited idiom blends. *Memory and Cognition*, *25*(1), 57–71. https://doi.org/10.3758/BF03197285

Cutting, J. C., & Ferreira, V. S. (1999). Semantic and phonological information flow in the production lexicon. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*(2), 318.

Czypionka, A., Golcher, F., Błaszczak, J., & Eulitz, C. (2019). When verbs have bugs: lexical and syntactic processing costs of split particle verbs in sentence comprehension. *Language, Cognition and Neuroscience*, *34*(3), 326–350. https://doi.org/10.1080/23273798.2018.1539756

Dehé, N. (2001). Transitive particle verbs in {English}: The neutral order. Evidence from speech production. *Structural Aspects of Semantically Complex Verbs*, 165–189.

Dehé, N., Jackendoff, R., McIntyre, A., & Urban, S. (2012). *Verb-particle explorations* (Vol. 1). Walter de Gruyter.

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review*, *93*(3), 283.

Di Sciullo, A.-M., & Williams, E. (1987). *On the definition of word* (Vol. 14). Springer.

Farrell, P. (2005). English verb-preposition constructions : constituency and order. *Language*, 96–137. https://www.jstor.org/stable/4489855

Friederici, A. D., Pfeifer, E., & Hahne, A. (1993). Event-related brain potentials during natural speech processing: effects of semantic, morphological and syntactic violations. *Cognitive Brain Research*, *1*(3), 183–192. https://doi.org/10.1016/0926-6410(93)90026-2

Geerts, G., Haeseryn, W., de Rooij, J., & van den Toorn, M. C. (1984). *Algemene Nederlandse Spraakkunst (Groningen and Leuven, Wolters)*.

Hanna, J., Cappelle, B., & Pulvermüller, F. (2017). Spread the word: MMN brain response reveals whole-form access of discontinuous particle verbs. *Brain and Language*, *175*(June 2016), 86–98. https://doi.org/10.1016/j.bandl.2017.10.002

Hanna, J., & Pulvermüller, F. (2014). Neurophysiological evidence for whole form retrieval of complex derived words: A mismatch negativity study. *Frontiers in Human Neuroscience*, *8*(November), 1–13. https://doi.org/10.3389/fnhum.2014.00886

Hanna, J., & Pulvermüller, F. (2018). Congruency of Separable Affix Verb Combinations Is Linearly Indexed by the N400. *Frontiers in Human Neuroscience*, *12*(May), 1–10. https://doi.org/10.3389/fnhum.2018.00219

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. *Journal of Memory and Language*, *58*(2), 214–238. https://doi.org/10.1016/j.jml.2007.07.003

Hartsuiker, R. J., & Westenberg, C. (2000). Persistence of word order in written and spoken sentence production. *Cognition*, *75*, 27–39.

Huang, J., Pickering, M. J., Chen, X., Cai, Z., Wang, S., & Branigan, H. P. (2019). Does language similarity affect representational integration? *Cognition*, *185*(March 2018), 83–90. https://doi.org/10.1016/j.cognition.2019.01.005

Huang, J., Pickering, M. J., Yang, J., Wang, S., & Branigan, H. P. (2016). The independence of syntactic processing in Mandarin: Evidence from structural priming. *Journal of Memory and Language*, *91*, 81–98. https://doi.org/10.1016/j.jml.2016.02.005

Isel, F., Hahne, A., Maess, B., & Friederici, A. D. (2007). Neurodynamics of sentence interpretation: ERP evidence from French. *Biological Psychology*, *74*(3), 337–346. https://doi.org/10.1016/j.biopsycho.2006.09.003

Jackendoff, R. (1995). The boundaries of the lexicon. In *Idioms: Structural and Psychological Perspectives* (pp. 133–165).

Jackendoff, R. (2002). *Foundations of language: Brain, meaning, grammar, evolution*. Oxford University Press.

Jaeger, T. F., & Snider, N. (2008). Implicit learning and syntactic persistence : Surprisal and Cumulativity. *Proceedings of the 30th Annual Meeting of the Cognitive Science Society (CogSci08)*, *January 2014*, 1061–1066.

Johnson, K. (1991). Object positions. *Natural Language & Linguistic Theory*, *9*(4), 577–636.

Keuleers, E., Brysbaert, M., & New, B. (2010). SUBTLEX-NL: A new measure for Dutch word frequency based on film subtitles. *Behavior Research Methods*, *42*(3), 643–650. https://doi.org/10.3758/BRM.42.3.643

Konopka, A. E., & Bock, K. (2009). Lexical or syntactic control of sentence formulation? Structural generalizations from idiom production. *Cognitive Psychology*, *58*(1), 68–101. https://doi.org/10.1016/j.cogpsych.2008.05.002

Leminen, A., Leminen, M., Kujala, T., & Shtyrov, Y. (2013). Neural dynamics of inflectional and derivational morphology processing in the human brain. *Cortex*, *49*(10), 2758–2771. https://doi.org/10.1016/j.cortex.2013.08.007

Levelt, W. J. M. (1989). *Speaking: form intention to articulation*. Cambridge: Massachusetts Institute of Technology.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22*, 1–75.

Lüdeling, A. (2001). *On particle verbs and similar constructions in German*. Stanford Univ Center for the Study.

Messenger, K., Branigan, H. P., McLean, J. F., & Sorace, A. (2012). Is young children's passive syntax semantically constrained? Evidence from syntactic priming. *Journal of Memory and Language*, *66*, 568–587.

Munakata, Y., & Pfaffly, J. (2004). Hebbian learning and development. *Developmental Science*, *7*(2), 141–148. https://doi.org/10.1111/j.1467-7687.2004.00331.x

Neeleman, A., & Weerman, F. (1993). The balance between syntax and morphology: Dutch particles and resultatives. *Natural Language & Linguistic Theory*, *11*(3), 433–475.

Piai, V., Meyer, L., Schreuder, R., & Bastiaansen, M. C. M. (2013). Sit down and read on: Working memory and long-term memory in particle-verb processing. *Brain and Language*, *127*(2), 296–306. https://doi.org/10.1016/j.bandl.2013.09.015

Pickering, M. J., & Branigan, H. P. (1998). The Representation of Verbs: Evidence from Syntactic Priming in Language Production. *Journal of Memory and Language*, *39*, 633–651.

Pickering, M. J., & Ferreira, V. S. (2008). Structural Priming: A Critical Review. *Psychological Bulletin*, *134*(3), 427–459.

Pulvermüller, F., & Shtyrov, Y. (2006). Language outside the focus of attention: The mismatch negativity as a tool for studying higher cognitive processes. *Progress in Neurobiology*, *79*(1), 49–71. https://doi.org/10.1016/j.pneurobio.2006.04.004

Roelofs, A. (1996). Serial order in planning the production of successive morphemes of a word. *Journal of Memory and Language*, *35*(6), 854–876. https://doi.org/10.1006/jmla.1996.0044

Roelofs, A. (1998). Rightward incrementality in encoding simple phrasal forms in speech production: Verb-particle combinations. *Journal of Experimental Psychology: Learning*

Memory and Cognition, *24*(4), 904–921. https://doi.org/10.1037/0278-7393.24.4.904

Rowland, C. F., Chang, F., Ambridge, B., Pine, J. M., & Lieven, E. V. M. (2012). The development of abstract syntax: Evidence from structural priming and the lexical boost. *Cognition*, *125*(1), 49–63. https://doi.org/10.1016/j.cognition.2012.06.008

Santesteban, M., Pickering, M. J., & McLean, J. F. (2010). Lexical and phonological effects on syntactic processing: Evidence from syntactic priming. *Journal of Memory and Language*, *63*(3), 347–366. https://doi.org/10.1016/j.jml.2010.07.001

Scheepers, C., Raffray, C. N., & Myachykov, A. (2017). The lexical boost effect is not diagnostic of lexically-specific syntactic representations. *Journal of Memory and Language*, *95*, 102–115. https://doi.org/10.1016/j.jml.2017.03.001

Schoonbaert, S., Hartsuiker, R. J., & Pickering, M. J. (2007). The representation of lexical and syntactic information in bilinguals: Evidence from syntactic priming. *Journal of Memory and Language*, *56*(2), 153–171. https://doi.org/10.1016/j.jml.2006.10.002

Shin, J. A., & Christianson, K. (2012). Structural Priming and Second Language Learning. *Language Learning*, *62*(3), 931–964. https://doi.org/10.1111/j.1467-9922.2011.00657.x

Shtyrov, Y., & Pulvermüller, F. (2002). Neurophysiological evidence of memory traces for words in the human brain. *NeuroReport*, *13*(4), 521–525. https://doi.org/10.1097/00001756-200203250-00033

Sprenger, S. A., Levelt, W. J. M., & Kempen, G. (2006). Lexical access during the production of idiomatic phrases. *Journal of Memory and Language*, *54*(2), 161–184. https://doi.org/10.1016/j.jml.2005.11.001

Thothathiri, M., & Snedeker, J. (2008). Give and take: Syntactic priming during spoken language comprehension. *Cognition*, *108*(1), 51–68. https://doi.org/10.1016/j.cognition.2007.12.012

Tooley, K. M., & Bock, K. (2014). On the parity of structural persistence in language production and comprehension. *Cognition*, *132*(2), 101–136. https://doi.org/10.1016/j.cognition.2014.04.002

Van Dale, U. (2015). *Van Dale Groot Woordenboek*. http://vandale.ugent.be/

Van de Cavey, J., & Hartsuiker, R. J. (2016). Is there a domain-general cognitive structuring system? Evidence from structural priming across music, math, action descriptions, and language. *Cognition*, *146*, 172–184. https://doi.org/10.1016/j.cognition.2015.09.013

Zeller, J. (2001). How syntax restricts the lexicon: particle verbs and internal arguments. *Linguistische Berichte*, *188*, 459–492.

Zhang, C., Bernolet, S., & Hartsuiker, R. J. (2021). Are there segmental and tonal effects on syntactic encoding? Evidence from structural priming in Mandarin. In *Journal of Memory and Language* (Vol. 119). https://doi.org/10.1016/j.jml.2021.104220