

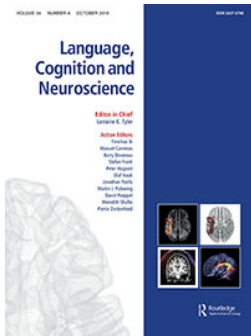
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Processing derived verbs: the role of motor-relatedness and type of morphological priming

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ABSTRACT

There is no consensus on whether derived words are decomposed or processed holistically, and on which factors this depends. Using overt visual priming with lexical decision involving Dutch derived particle verbs, we manipulated three factors: semantic transparency of the derived words, motor-relatedness of the simple verb constituent, and type of morphological priming. Experiments 1 and 2 (using simple verbs primed by their derivations or vice versa) showed overall facilitatory morphological priming effects, independent of transparency or motor-relatedness. In Experiment 3 (using priming between the derivation and a word semantically related to its stem), only transparent motor-related derivations were primed. The combined results suggest that the processing of derivations is influenced by priming type: constituent priming (Exp. 1 & 2) may induce a bias towards a decompositional processing strategy, possibly by directing attention to the stimuli's morphological structure. The role of motor-relatedness is discussed in the context of embodied cognition theory.

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Introduction


After decades of research into the processing of derivations, the question whether derived words are decomposed into their constituent parts or processed holistically still remains unresolved. Derivations are words such as *rewrite*, in which a stem (e.g. *write*) is combined with an affix (e.g. *re-*) to form a new, morphologically complex word. The processing of derivations has often been investigated in behavioural priming studies. In such studies, a target (e.g. a morphologically simple word such as *write*) is preceded by a related prime (e.g. a morphologically complex word such as *rewrite*) or an unrelated prime (e.g. *refit*). The underlying idea is that, if derivations are decomposed into their parts during processing (e.g. into *re-* and *write*), access of the stem (*write*) through decomposition of the prime (*rewrite*) should heighten the activation level of the stem and thus facilitate its recognition in the subsequently presented target. This should, for instance, become visible in reaction times (like lexical decision times) on the target. In contrast, if the complex word is not decomposed, but processed holistically, its representation in the mental lexicon should be separate from that of the stem and its access should therefore be independent of that of the stem. Thus, priming the derivation's stem should not facilitate its recognition. Since purely form-

related prime-target pairs are usually associated with either significant inhibition or no significant priming, any facilitation effects found for morphologically related prime-target pairs are not supposed to be due to their overlap in form (e.g. Marslen-Wilson, Tyler, Waksler, & Older, 1994; Smolka, Komlósi, & Rösler, 2009; Smolka, Preller, & Eulitz, 2014; Zwitserlood, 1994). A more detailed discussion of the potential mechanisms leading to morphological priming effects can be found in the General Discussion.

In the present study, overt visual priming is used, i.e. the prime is presented long enough to be consciously perceived and the stimuli are presented visually (rather than auditorily). This differs from masked visual priming, in which the prime is presented for a very short duration and followed by a mask, such that the prime is not consciously perceived. Since overt and masked priming may reflect and lead to different types of processing, our literature review will be limited to overt priming.

In overt priming studies, semantic transparency and the type of language have been found to influence whether or not derivations show morphological priming effects (e.g. Marslen-Wilson et al., 1994). In English, semantically transparent derivations such as *rewrite* (in which the meaning of the derivation can be

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deduced from the meaning of its parts, *re-* and *write*) are usually found to prime their stems (or vice versa), suggesting they are decomposed. In contrast, semantically opaque derivations such as *understand* (in which the meaning of the derivation cannot be deduced from its parts, *under-* and *stand*) often do not show a morphological priming effect. In German, however, several overt priming studies have found morphological priming effects for both semantically transparent and opaque derivations, suggesting that both may be decomposed in German (e.g. Smolka et al., 2009, 2014). Smolka and colleagues explained this discrepancy with respect to findings in English by referring to the difference in “morphological richness” between German and English. German, compared with English, has a richer morphological system, i.e. word-formation processes such as derivation are more productive in German (Dressler, 2005; Duncan, Casalis, & Colé, 2009; Haman, Zevenbergen, Andrus, & Chmielewska, 2009; Hickmann, Hendriks, Roland, & Liang, 1996). The morphological richness of German may enhance the use of decomposition as a default strategy, leading to decomposition even of opaque derivations.

However, this may not be the whole story, as evidenced by some fMRI studies on German and Dutch (which has a comparably elaborate derivational system as German). These studies have found no evidence for decomposition of opaque derivations (German: Rüschemeyer, Brass, & Friederici, 2007; Dutch: De Grauwe, Willems, Rueschemeyer, Lemhöfer, & Schriefers, 2014). More specifically, no evidence was found of increased activation of motor and/or somatosensory cortical areas upon presentation of semantically opaque derivations with a motor-related stem. Increased activation of these areas would have been expected if the motor-related stems of these derivations had been semantically accessed, i.e. if these opaque derivations had been decomposed. Conversely, an fMRI/overt priming study on English has found some evidence for decomposition of opaque derivations (Bozic, Marslen-Wilson, Stamatakis, Davis, & Tyler, 2007): morphologically related words (both transparent and opaque) produced both a repetition suppression effect in the left inferior frontal gyrus and a behavioural priming effect. These effects were attributed to the use of long-lag priming (as opposed to immediate overt priming).

Thus, differences in semantic transparency and the morphological richness of the languages tested cannot provide a full explanation of the results of overt visual priming studies on derivations. Other factors may play a role, such as the type of derived words used in these studies and the precise priming method used. In the current study, we investigate what impact some of

these differences have on the obtained priming effects, and whether they may therefore have been responsible for the varying results of previous studies. We concentrate on a factor related to the priming paradigm, i.e. type of morphological priming (“constituent priming” vs. “semantic stem priming”) and a stimulus-related factor, i.e. motor-relatedness of the verb stem. Below, these factors are elaborated.

We would like to note that the word “stem” can be used in different ways. Sometimes it is used to refer to a form to which (any kind of) affixes can be attached; sometimes it is used to refer to a form to which *inflectional* affixes can be attached. In either sense, it can be morphologically complex, i.e. it may consist of a root plus one or more affixes. We use “stem” in the first, more general sense.

Type of morphological priming

In the overt priming studies mentioned above, two types of morphological priming were used. The first one, constituent priming, is the most common one. In this paradigm, a complex word (e.g. *understand*) primes its stem (e.g. *stand*), or vice versa (Marslen-Wilson et al., 1994; Rastle, Davis, Marslen-Wilson, & Tyler, 2000). The second priming type, which we will call “semantic stem priming”, has been used in some studies on the processing of derivations and compounds (Dutch: Sandra, 1990; Zwitserlood, 1994; Zwitserlood, Bolwiender, & Drews, 2005). In this paradigm, the prime (e.g. *sit*) is semantically related to the stem or one of the constituents of the complex word target (e.g. *stand* in *understand*), or vice versa.

While, in principle, one could be led to assume that both priming methods should give rise to the same results, a review of the findings suggests that this might not be completely true. Both methods show morphological priming for transparent derivations, regardless of the type of language (English: Feldman & Soltano, 1999; Feldman, Soltano, Pastizzo, & Francis, 2004; Gonnerman, Seidenberg, & Andersen, 2007; Marslen-Wilson et al., 1994; Rastle et al., 2000; French: Longtin, Segui, & Hallé, 2003; Dutch: Sandra, 1990; Zwitserlood, 1994; Zwitserlood et al., 2005). Opaque derivations generally show no morphological priming, with one exception: studies on German and Dutch using morphological priming did also demonstrate priming for opaque stimuli (Lüttmann, Zwitserlood, & Bölte, 2011; Smolka et al., 2009, 2014; Zwitserlood, 1994; see also Smolka, Gondan, & Rösler, 2015, for electrophysiological evidence confirming these behavioural results). Thus, at least for morphologically rich languages and opaque stimuli, the two types of priming might not be interchangeable.

The only study in which the two types of priming have been compared directly (Zwitzerlood, 1994) suggests that this may be the case, at least for compounds. In this study, Dutch compounds of various degrees of transparency were presented for lexical decision in two overt visual priming experiments, one using the constituent priming paradigm, the other using the semantic stem priming paradigm. The constituent priming experiment showed a significant priming effect for “truly opaque compounds” (i.e. compounds whose meaning cannot be derived from the meaning of any of their constituents). In contrast, no priming effect was found when these compounds were used as primes for semantic associates of their constituents as targets (i.e. in semantic stem priming).

However, it is difficult to draw clear conclusions from Zwitzerlood’s (1994) results for the current study. First, only a small number of truly opaque compounds was tested, leading to an unbalanced design in terms of number of items: Each participant saw 1–2 (Exp. 1) or 4 (Exp. 2) truly opaque compounds versus 7 (Exp. 1) or 11 (Exp. 2) “fully transparent compounds” (i.e. compounds whose meaning is related to the meaning of all their constituents). Also, it is unclear whether the stimulus characteristics were matched across these two conditions. As a result, fully transparent and truly opaque compounds could not be compared directly in the analyses. Second, the stimulus sets used in the two experiments were overlapping but not entirely the same. Finally, compounds may not be processed in the same way as derived verbs, as compounds consist of two full, independent words, while derived verbs consist of a full, independent verb and an affix (in our case prefix). The current study is the first to systematically contrast the two types of morphological priming, using the same stimulus set (transparent and opaque derived verbs) in a balanced design.

Motor-relatedness

We also investigated the role of motor-relatedness in the processing of derivations, i.e. the degree to which a word refers to a movement performed with specific muscles. The manipulation of motor-relatedness versus non-motor-relatedness of the stem of complex verbs has been used in fMRI studies on the processing of opaque morphologically complex words. The argumentation behind this manipulation is that, if an opaque complex verb with a motor-related stem does activate the corresponding motor areas in the brain, then the complex verb must have been decomposed in its motor-related stem and its pre- or suffixes. In behavioural terms, it could be the case that motor-related stems “stand out”

more in the processing of complex verbs than non-motor-related stems because the former stems refer to concrete actions. Originally motivated by the (later abandoned) plan to design the present behavioural experiments in parallel with an fMRI experiment, we addressed this issue by manipulating the motor-relatedness of the stem.

Motor-relatedness has been used as a variable in many fMRI studies investigating the involvement of the motor cortex in the processing of motor-related words (e.g. De Grauwe et al., 2014; Hauk, Johnsrude, & Pulvermüller, 2004; Raposo, Moss, Stamatakis, & Tyler, 2009; Rüschemeyer et al., 2007). The results of many of these studies provide support for embodied cognition theory (Barsalou, 2008). According to this theory, language is grounded in bodily action and perception: Accessing the meaning of a word involves simulation of the actions and/or sensory experiences referred to by the word in the corresponding neural motor and sensory systems. In line with this theory, several other sensory- and/or motor-related variables (all of which are measured through ratings) have been found to play a role in word recognition: “body-object interaction” (BOI), i.e. the ease with which the human body can physically interact with a noun’s referent (Bennett, Burnett, Siakaluk, & Pexman, 2011; Siakaluk, Pexman, Aguilera, Owen, & Sears, 2008; Siakaluk, Pexman, Sears, et al., 2008), “relative embodiment”, i.e. the degree to which the meaning of a verb involves the human body, including actions, passive movements and internal sensorimotor states (Sidhu, Kwan, Pexman, & Siakaluk, 2014), and “sensory experience rating” (SER) or “maximum perceptual strength”, two variables indexing the degree to which a word evokes sensory or perceptual experiences (for details on the SER, see Bonin, Méot, Ferrand, & Bugaïska, 2014; Juhasz & Yap, 2013; Juhasz, Yap, Dicke, Taylor, & Gullick, 2011; for details on maximum perceptual strength, see Connell & Lynott, 2012). All these variables differ slightly in their exact definitions, but presumably have a large overlap in the sense that they distinguish words that refer to concrete sensory and/or motor-related experiences from those that do not. Words with a higher degree of BOI, relative embodiment, SER, or maximum perceptual strength were found to elicit faster lexical decision times, even when the influence of other word recognition variables, including semantic variables such as concreteness and/or imageability, was controlled for. This facilitation was explained by referring to embodied cognition theory: Words associated with a higher degree of sensory- and/or motor-related content may be easier to simulate and/or evoke more semantic activation than words whose meaning is less grounded in sensory or bodily experience.

Recently, the effects of the SER and BOI variables have also been used to investigate whether English compounds are morphologically decomposed or not (Kuperman, 2013). Lexical decision times to compounds (whose semantic transparency was not taken into account) were found to be influenced by the degree of SER of the compounds as a whole, but not by the degree of SER of their constituents or the degree of BOI of the compounds or their constituents. In contrast, constituents presented in isolation did show an effect of degree of SER and BOI. This was interpreted as evidence that compounds are not decomposed (see also De Grauwe et al., 2014, for Dutch, and Rüschemeyer et al., 2007, for German, for two fMRI studies with a similar logic).

All the behavioural studies mentioned above have looked at the relation between sensory- or motor-related variables and lexical decision times in a non-priming context. It is not clear yet what the effect of these variables on lexical decision times would be in a priming context. Possibly, decomposition is stimulated in a priming context, as suggested by a comparison of studies with and without priming (e.g. Bozic et al., 2007 vs. Rüschemeyer et al., 2007; De Grauwe et al., 2014; see above). If a higher degree of motor-relatedness leads to faster lexical-semantic access (due to, for example, greater ease of simulation or increased semantic activation of motor-related content) and decomposition is stimulated in a priming context, then motor-related constituents of morphologically complex words may be activated more easily than non-motor constituents in a priming context. Thus, complex words with motor-related constituents may be decomposed more easily, leading to an increased priming effect for these words. This is an aspect that, to our knowledge, has not yet been addressed in studies on morphological priming.

The present study

In the present study, our first aim was to find out whether or not Dutch semantically transparent and opaque derived verbs show a difference in overt priming effects, an issue that has so far not been resolved in the overt priming literature. Second, we investigated whether different priming types, i.e. constituent versus semantic stem priming, give rise to the same results. In the literature on derivation processing, the different types of priming are sometimes referred to as if they were equivalent (Amenta & Crepaldi, 2012; Taft, 2003), but they have, in some cases, led to conflicting results (see, e.g. Zwitserlood, 1994), and a systematic investigation of differences between these methods is lacking. Third, we investigated whether motor-relatedness modulates the priming effect, for example by

leading to increased facilitation for derived verbs containing motor-related stems. As a replication of the many previous overt priming studies in English, Dutch and German, we ran a constituent priming experiment with derived primes and simple targets (Experiment 1). To make sure that our morphological priming results were robust and consistent, we ran another constituent priming experiment with the same stimuli but with reversed order of primes and targets (Experiment 2). Finally, the semantic stem priming experiment (Experiment 3) allowed us to compare constituent priming and semantic stem priming. Each experiment contained both a transparent versus opaque derivation contrast and a motor-related versus non-motor-related contrast. As discussed in the introduction, the results of constituent priming studies in the literature show some inconsistencies, while semantic stem priming does not. In all three experiments, the derived words were Dutch particle verbs, i.e. verbs with a separable prefix, such as *opschrijven* (“to write down”). Particles can be separated from particle verb stems in certain circumstances, such as in main clauses, e.g. *Zij schrijft het op* (“She writes it down”). In each experiment, half of the derived verbs were semantically transparent (e.g. *opschrijven* “to write down” with stem *schrijven* “to write”), the other half were semantically opaque (e.g. *toekennen* “to award” with stem *kennen* “to know”). In each group, half of the derived verbs contained a motor-related stem, whereas the other half contained a non-motor-related stem. Finally, each derived verb was paired with a related and an unrelated word, which served either as a target (Experiment 1) or a prime (Experiments 2 and 3). Thus, a 2 (Transparency: Transparent vs. Opaque) by 2 (Motor-Relatedness: Motor vs. Non-Motor) by 2 (Prime Relatedness: Related vs. Unrelated Prime) design was used in each experiment.

Experiment 1: constituent priming, complex primes

In Experiment 1, we looked at whether complex verbs (e.g. *opschrijven* “to write down”) primed simple verbs that were either morphologically related (the prime stems, e.g. *schrijven* “to write”) or unrelated (e.g. *rijden* “to drive”). Furthermore, we assessed the role of the semantic transparency of the derived verbs and the motor-relatedness of the stems.

Method

Participants

Twenty-nine Dutch native speakers participated. All of them were or had been students at an institution for

higher education. After exclusion (see below), 28 participants (26 female; 23 right-handed) remained. Their mean age was 20.7 years (SD: 2.2; range: 18–26). They were all born in the Netherlands, had Dutch as their mother tongue, were raised monolingually, and reported having no reading or hearing disorders. They all signed a written consent form in accordance with the Declaration of Helsinki.

Materials

Primes and targets. For this experiment, 88 Dutch derived verbs were chosen as primes. Each verb consisted of a stem (e.g. *schrijven* “to write”) preceded by a particle (e.g. *op* “up, on”), yielding a so-called particle verb (e.g. *opschrijven* “to write down”). Half of the particle verbs (44) contained a stem with a motor-related meaning (e.g. *schrijven* “to write” in *opschrijven* “to write down”), the other half (44) contained a stem whose meaning was not motor-related (e.g. *kennen* “to know” in *toekennen* “to award”). In each of these two sets, half of the complex verbs (22) were semantically transparent, while the other half (22) were opaque (e.g. *toekennen*).

The selection of these verbs was based on ratings obtained in two web-based studies: (a) a familiarity and transparency rating study, and (b) a motor-relatedness rating study. Participants in these studies were from the same population as the main experiments but did not participate in the main experiments or in any of the other rating studies. In the first study, 21 Dutch participants rated 192 complex verbs in terms of their familiarity and their transparency (i.e. how strongly related the meaning of the complex verb was to that of its stem) on two separate scales from 1 to 5 (familiarity: 1 “never seen, heard or used” – 5 “seen, heard or used very often”; transparency: 1 “not related at all” – 5 “strongly related”). In the motor-relatedness study, 20 Dutch participants rated 159 stems of complex verbs, indicating to which degree each verb referred to a movement they could perform themselves using specific muscles, for example arm, leg or facial muscles (on a scale from 1 “no specific muscles necessary” to 5 “specific muscles necessary”). Secondly, they were asked to indicate which specific muscles (such as arm or hand muscles, leg muscles, facial or head muscles) could be used to perform the movement indicated by the verb (if any). On the basis of the results of the rating studies, the 88 prime verbs for the present study were selected. The characteristics of these prime verbs are reported in Table 1.

As confirmed by ANOVAs, motor and non-motor conditions differed significantly in terms of Motor-Relatedness ($F(1,84) = 657.26, p < .001$), but were matched in terms of Transparency and Familiarity ($ps > .28$).

Transparent and opaque conditions differed significantly in terms of Transparency ($F(1,84) = 764.93, p < 0.001$), but were matched in terms of Motor-Relatedness ($F < 1$). Although all conditions contained highly familiar particle verbs, it could not be avoided that opaque verbs were significantly less familiar than transparent verbs ($F(1,84) = 17.80, p < .001$). Finally, all conditions were matched in terms of particle verb and stem length (number of letters; $F_s < 1$), particle verb and stem frequency¹ (ln of Celex lemma frequency: $ps > .22$; see Baayen, Piepenbrock, & Gulikers, 1995), and morphological family size (ln of Celex morphological family size: $F_s < 1$).

For each particle verb prime, a morphologically related target was selected: the stem of the particle verb prime (e.g. *schrijven* “to write” with prime *opschrijven* “to write down”; *kennen* “to know” with prime *toekennen* “to award”). The characteristics of these targets are reported in Table 1.

Each particle verb prime was also paired with a particle verb prime unrelated to the target (e.g. *wegrijden* “to drive away” with related prime *opschrijven*; *ophouden* “to stop” with related prime *toekennen*). Related and unrelated primes were matched across all four prime conditions in terms of frequency (ln of Celex lemma frequency: $ps > .60$) and length (number of letters: $ps > .11$). Related and unrelated prime characteristics are reported in Table 2.

The six prime categories (resulting from crossing the factors of Transparency and Motor-Relatedness and adding the factor of Prime-Relatedness) yields the $2 \times 2 \times 2$ design presented in Table 3. This table also contains examples of the stimuli (see Appendix A for a list of all experimental stimuli).

Fillers. To distract participants’ attention from the complex verbs, 88 simple verbs were selected as filler primes and paired with 88 filler targets (44 nouns, 44 verbs). Half of the pairs were morphologically related (e.g. *dekken* “to cover” with target *ontdekken* “to discover”), half of them were not (e.g. *weigeren* “to refuse” with target *bakker* “baker”). Thus, related targets were not only present with the (complex) experimental primes, but also with the (simple) filler primes.

Pseudo-words. To obtain an equal number of word and pseudo-word targets, 176 phonotactically legal pseudo-words were created by changing one or more letters from existing Dutch words. The pseudo-words were verb-like (ending in the Dutch infinitival suffix *-en*) or noun-like (ending in a nominal suffix such as *-er* or having no suffix) and could be morphologically simple (e.g. *nalmen*, *kark*) or complex (consisting of existing affixes and non-existing stems; e.g. *ontstuiten*, *sponker*).

Table 1. Characteristics of complex verbs and their stems.

	Rated motor-relatedness	Rated transparency	Rated familiarity	Length	Frequency	Morphological family size	Stem length	Stem frequency
Motor transparent	4.20 (.37)	4.05 (.44)	4.68 (.26)	9.09 (1.41)	5.44 (.93)	4.32 (2.01)	6.27 (.98)	8.21 (1.23)
Motor opaque	4.05 (.61)	1.64 (.41)	4.30 (.35)	8.95 (1.29)	5.67 (1.35)	4.09 (1.47)	6.23 (1.07)	8.46 (1.81)
Non-motor transparent	1.34 (.50)	4.08 (.38)	4.57 (.30)	9.05 (1.09)	5.74 (.90)	4.24 (1.94)	6.41 (1.01)	8.55 (1.34)
Non-motor opaque	1.47 (.47)	1.79 (.36)	4.30 (.48)	8.91 (1.31)	5.38 (1.32)	4.38 (2.23)	6.14 (.77)	8.20 (2.00)

Notes: Means of characteristics shown (standard deviations in parentheses). Pre-tests: ratings on a scale of 1–5, with 1 = low degree and 5 = high degree of respective feature. Length: in letters. Frequency: ln-transformed Celex frequency counts.

The same proportion of noun- and verb-like pseudo-words was used as for real words. In addition, the same affixes were used as for the word targets, in the same proportions. The pseudo-words were paired with 88 morphologically simple verb primes and 88 particle verb primes.

All real words used in this experiment were presented in their citation form.

Lists. Four lists were constructed by pseudo-randomising two lists in two different orders each. The two lists each contained 88 experimental prime/target pairs (half of which were related prime/target pairs), 88 filler prime/target pairs (half of which were related prime/target pairs) and 176 prime/pseudo-word target pairs. The lists were set up such that all 176 experimental prime/target pairs were counterbalanced over the two lists but participants saw each prime and target only once. Thus, each list contained 352 prime/target pairs, 88 of which (25%) involved a related prime and target. Each of the two lists was pseudo-randomised in two different orders such that no prime or target type was presented on more than three consecutive trials, resulting in four different lists. An equal number of participants was assigned to each list.

Procedure

Participants were told (first orally, then through written instructions) that, in each trial, two letter strings would

Table 2. Prime characteristics: Experiment 1 and 2.

	Related primes		Unrelated primes	
	Length	Frequency	Length	Frequency
<i>Experiment 1</i>				
Motor transparent	9.09 (1.41)	5.44 (.93)	9.00 (1.20)	5.32 (1.40)
Motor opaque	8.95 (1.29)	5.67 (1.35)	8.95 (1.59)	5.55 (1.44)
Non-motor transparent	9.05 (1.09)	5.74 (.90)	9.00 (1.15)	5.59 (1.13)
Non-motor opaque	8.91 (1.31)	5.38 (1.32)	9.36 (1.36)	5.53 (1.81)
<i>Experiment 2</i>				
Motor transparent	6.27 (.98)	8.21 (1.23)	6.32 (1.17)	8.27 (1.30)
Motor opaque	6.23 (1.07)	8.46 (1.81)	6.32 (1.04)	8.39 (1.45)
Non-motor transparent	6.41 (1.01)	8.55 (1.34)	6.41 (1.01)	8.32 (1.48)
Non-motor opaque	6.14 (.77)	8.20 (2.00)	6.36 (1.00)	8.06 (1.48)

Notes: Means of characteristics shown (standard deviations in parentheses). Length: in letters. Frequency: ln-transformed Celex frequency counts.

appear on the screen in close succession. They were to read the letter strings and indicate whether the second word in each trial (the target) was a real Dutch word or not. They were asked not to react to the first word (the prime). If the target was an existing Dutch word, participants were to press a button with the index finger of their dominant hand; if not, the other hand should be used. Participants were asked to respond as quickly and accurately as possible.

The stimuli were presented in 24-point, black, lower-case letters in Arial font against a light-grey background using Presentation software (developed by Neurobehavioral Systems, www.neurobs.com) on a personal computer. Participants were seated approximately 60 cm from the computer monitor.

Each trial began with a fixation cross displayed at the centre of the screen for 500 ms. Then a blank screen was presented for 100 ms, followed by the prime, which remained at the centre of the screen for 300 ms. A blank screen appeared for 100 ms, after which the target was presented just below the centre of the screen² for 500 ms (or until the participant's response, if it was given within these 500 ms). If the participant did not respond within these 500 ms, a blank screen appeared. Upon participant response or at 3000 ms after target onset, another blank screen was presented for 1000 ms before the next trial started.

Before the experiment, participants were familiarised with the task by completing a practice block of 20 prime-target pairs not used in the experiment, with similar proportions of the different prime and target

Table 3. Experiment 1: Design and examples of stimuli.

		Target	Related prime	Unrelated prime
Motor	Transparent	schrijven (to write)	opschrijven (to write down)	wegrijden (to drive away)
	Opaque	vreten (to devour)	uitvreten (to be up to)	aansmeren (to palm off)
Non-motor	Transparent	denken (to think)	nadenken (to reflect, consider)	opheffen (to raise)
	Opaque	kennen (to know)	toekennen (to award)	ophouden (to stop)

types as in the experimental stimulus list. After this block, they could ask questions if necessary. The actual experiment consisted of eight blocks of 44 prime/target pairs. Each block started with three filler and/or pseudo-word stimuli. In between blocks, participants were allowed to take a break. The experiment lasted approximately 30 min.

Additional tests. After the main experiment, two spelling tests and one vocabulary test were administered. These allowed us to assess the potential influence of individual differences in spelling and vocabulary proficiency on the results of the main experiment. Such an influence was found by Andrews and Lo (2013). In their study, participants with a “semantic profile” (relatively higher vocabulary than spelling proficiency) showed increased priming for transparent compared to opaque derivations. In contrast, participants with an “orthographic profile” (higher spelling than vocabulary proficiency) showed similar priming effects for both types of derivations.

The first test we used was a spelling recognition test. Ninety Dutch words were presented visually, half of which were spelled correctly, and half of which were spelled incorrectly. Correct and incorrect words were pseudo-randomised such that no more than three words of each condition appeared consecutively. Participants were to indicate for each word whether it was spelled correctly or not by pressing the corresponding button on a button box.

The second spelling test was a dictation containing 27 Dutch words. The words were spoken by a young female native speaker of Dutch. Participants wore headphones, and were instructed to type each word they heard. They could repeat each stimulus up to four times by pressing the appropriate button.

The vocabulary test contained 60 words. The stimuli were ordered in terms of frequency, starting with the most frequent stimulus word and ending with the least frequent word. Each word was shown together with an example sentence containing the word. In addition, each word was presented with four possible descriptions of the meaning of the word, one of which was correct. Participants were asked to indicate for each of the words shown which description conveyed the meaning of the word best by pressing the corresponding button on a button box. If they did not know the word, they could indicate this by pressing a fifth button.

The two spelling tests were based on a test created by Langereis and Elshout (n.d.). The vocabulary test was created by Andringa, Olsthoorn, Van Beuningen, Schoonen, and Hulstijn (2012). The three tests were run using Presentation software. Font and screen characteristics were the same as in the main experiment.

Participants were asked to respond as accurately as possible without time restriction. Together, the three tests took approximately 30 min.

Results and discussion

One participant was excluded because his mean reaction time to words was more than three standard deviations above the mean. Three experimental items (*opfokken* “to work up”, *oprapen* “to pick up” and *opzwellen* “to swell up”) were excluded from further analysis because their error percentage was more than three standard deviations above the mean. In the reaction time analyses, incorrectly answered trials (3.0%) were excluded, as were trials with an RT more than two standard deviations away from both a given item’s mean and a given participant’s mean for experimental targets (1.3%). Error percentages were arcsine-transformed before analysis to avoid problems of non-normal and/or non-homoscedastic data.

Mean RTs to words and pseudo-words were 528 ms (SD 85 ms) and 612 ms (SD 98 ms), respectively. On average, participants made 5.99% errors to words (SD 3.36%) and 3.81% errors to pseudo-words (SD 2.95%).

Repeated-measures analyses of variance (ANOVAs) were conducted on the RTs and error percentages for target words (see Table 4 for mean RTs and error percentages), with Transparency (Transparent vs. Opaque) and Motor-Relatedness (Motor vs. Non-Motor) as within-participants and between-items factors, and Prime Relatedness (Related vs. Unrelated) as within-participants and within-items factor. The main effect of Prime Relatedness in both RT and error analyses revealed that simple verbs (i.e. the targets) were responded to faster and with fewer errors when preceded by related primes (471 ms, 1.10% errors) than when preceded by unrelated primes (528 ms, 4.96% errors; RTs: $F_1(1,27) = 171.66$, $MSE =$

Table 4. Experiment 1: Mean reaction times and error percentages.

			Related	Unrelated	Priming
Motor	Transparent	RT (in ms)	467 (90)	525 (77)	58
		Errors (in %)	1.36 (4.36)	4.48 (6.71)	3.12
	Opaque	RT (in ms)	470 (92)	528 (90)	58
		Errors (in %)	.97 (2.86)	4.55 (7.21)	3.57
Non-motor	Transparent	RT (in ms)	471 (92)	522 (76)	51
		Errors (in %)	1.40 (3.49)	4.42 (7.44)	3.02
	Opaque	RT (in ms)	476 (82)	538 (81)	62
		Errors (in %)	.68 (2.51)	6.40 (9.10)	5.71
Mean	RT (in ms)	471 (88)	528 (80)	57	
	Errors (in %)	1.10 (3.35)	4.96 (7.61)	3.86	

Note: Standard deviations in parentheses.

1068.26, $p < .001$, $\eta_p^2 = .86$; $F_2(1,81) = 116.63$, $MSE = 1322.52$, $p < .001$, $\eta_p^2 = .59$; errors: $F_1(1,27) = 21.29$, $MSE = .109$, $p < .001$, $\eta_p^2 = .44$; $F_2(1,81) = 24.63$, $MSE = 0.08$, $p < .001$, $\eta_p^2 = .23$). Responses to verbs also tended to be faster when they were preceded by transparent than by opaque particle verbs (496 and 503 ms, respectively), although the main effect of Transparency was only marginally significant in the RT analysis by participants and not significant in the RT analysis by items ($F_1(1,27) = 3.42$, $MSE = 722.04$, $p = .075$, $\eta_p^2 = .11$; $F_2(1,81) = 1.39$, $MSE = 2126.46$, $p > .24$, $\eta_p^2 < .02$). None of the other effects or interactions were significant ($F_s < 1.33$, $p_s > .25$).

To find out whether individual differences in spelling and vocabulary skills affected the results (cf. Andrews & Lo, 2013), we ran multiple linear regression analyses using the results of the spelling and vocabulary tests as predictors. For this, the number of words was counted that contained at least one spelling error (dictation), whose spelling was judged incorrectly (spelling recognition) or whose meaning was judged incorrectly (vocabulary). The raw counts per participant were converted to rates per test per participant. The rates of the two spelling tests were averaged for each participant so as to arrive at one global spelling measure. A series of models was tested in which the resulting Spelling and Vocabulary Rates, Transparency, Motor-Relatedness and the interaction between Transparency and Motor-Relatedness were included as independent variables in varying combinations (see Appendix B). For the dependent variable, mean RTs for the related prime condition were subtracted from the mean RTs for the unrelated prime condition for each participant. The results showed no evidence of an influence of the spelling or vocabulary variables on the priming effect in any of the models ($p_s > .13$).

Experiment 1 shows clear priming by complex verb primes of their stems. This priming effect was not modulated by the motor-relatedness or transparency of the targets. Thus, similar results were obtained as in previous overt priming studies with German derivations (Lüttmann et al., 2011; Smolka et al., 2009, 2014), as opposed to overt priming studies with English derivations (Feldman & Soltano, 1999; Feldman et al., 2004; Gonnerman et al., 2007; Marslen-Wilson et al., 1994; Rastle et al., 2000). This indicates that transparent and opaque derivations do not differ in terms of constituent priming effects in a language with a rich derivational system. In addition, we found no evidence for the involvement of motor-relatedness in the processing of Dutch derivations, at least in the constituent priming paradigm. Finally, no evidence was found of an influence of individual differences on the priming effect, in contrast with

Andrews and Lo's (2013) findings, who, however, used masked priming.

As indicated above, the results of constituent priming studies reported in the literature are not fully consistent. Some studies show constituent priming only for transparent complex words, while others show constituent priming for both transparent and opaque complex words. Therefore, it appeared important to replicate the constituent priming results of Experiment 1. In this replication, we used the same materials as in Experiment 1, but reversed primes and targets (i.e. in Experiment 2, targets were complex words and primes their stems).

Experiment 2: constituent priming, complex targets

Method

Participants

Thirty Dutch native speakers participated. All participants were or had been students at an institution for higher education. After exclusion (see below), 28 participants (21 female; 26 right-handed) remained. Their mean age was 23.2 years (SD: 3.9; range: 18–32). They fulfilled the same criteria as the participants in the previous experiment. They all signed a written consent form in accordance with the Declaration of Helsinki. None of the participants had participated in Experiment 1.

Materials

Targets and primes. In this experiment, the simple targets of Experiment 1 were used as morphologically related primes, and the morphologically related particle verb primes of Experiment 1 were used as targets (see Table 5 for examples, Tables 1 and 2 for their characteristics, and Appendix A for a list of all experimental stimuli). Each target was also paired with an unrelated simple prime (see Tables 2 and 5). Related and unrelated primes were matched across all four target conditions in terms of length (number of letters: $p_s > .41$) and frequency (ln of Celex lemma frequency: $p_s > .36$).

Table 5. Experiment 2: Design and examples of stimuli.

		Target	Related prime	Unrelated prime
Motor	Transparent	opschrijven (to write down)	schrijven (to write)	rijden (to drive, ride)
	Opaque	uitvreten (to be up to)	vreten (to devour)	smeken (to beg)
Non- motor	Transparent	nadenken (to reflect, consider)	denken (to think)	houden (to hold)
	Opaque	toekennen (to award)	kennen (to know)	ademen (to breathe)

Fillers. As in Experiment 1, simple filler verbs were added to distract participants' attention from the complex verbs. Since the role of critical primes and targets was reversed in the current experiment, the same was done for the fillers.³ Eighty-eight simple verbs were therefore selected as filler targets. As in Experiment 1, half of these (44) were combined with morphologically related filler noun or verb primes (e.g. *danser* "dancer" with target *dansen* "to dance"), the other half (44) with unrelated filler primes (e.g. *bakker* "baker" with target *volgen* "to follow").

Pseudo-words. Most of the 176 phonotactically legal pseudo-words used in this experiment were either the same (44) as the pseudo-words used in Experiment 1 or differed from them by in a letter and/or an affix (130) in accordance with the following requirements: (1) they all ended in the infinitival suffix "-en"; (2) half of them (88) were simple pseudo-words, whereas the other half (88) were complex, in that they consisted of an existing particle and a non-existing stem. The same particles were used as for the experimental targets, in the same proportions.

For these pseudo-word targets, 176 unrelated noun and verb primes were selected. Noun and verb primes were chosen in the same proportion for each category of pseudo-word targets (simple and complex) as for word targets.

All real words used in this experiment were presented in their citation form.

Lists. Four lists were created according to the same criteria as those used in Experiment 1.

Procedure

The same procedure was used as in Experiment 1, both for the main experiment and for the spelling and vocabulary tests.

Results and discussion

Two participants were excluded because their percentage of errors to words and/or pseudo-words in the main experiment was more than three standard deviations above the mean. All experimental items were included, as none had error percentages more than three standard deviations above the mean. In the reaction time (RT) analyses, incorrectly answered trials were excluded (3.1%), as were trials for which the RT was more than two standard deviations away from both a given item's mean and a given participant's mean for

experimental targets (1.3%). Again, error rates were arcsine-transformed prior to their analysis.

Mean RTs to words and to pseudo-words were 556 ms (SD 88 ms) and 622 ms (SD 95 ms), respectively. Mean error percentages to words and to pseudo-words were 3.88% (SD 2.17%) and 3.25% (SD 2.82%), respectively.

For complex words, a similar pattern was found as in Experiment 1 (see Table 6 for mean RTs and error percentages). Particle verbs were responded to faster and with fewer errors when they were preceded by related primes (529 ms, 2.19% errors) than when they were preceded by unrelated primes (584 ms, 3.98% errors). The repeated-measures ANOVAs with factors Transparency, Motor-Relatedness and Prime Relatedness confirmed that both RTs and errors displayed a significant main effect of Prime Relatedness (RTs: $F_1(1,27) = 91.19$, $MSE = 1898.68$, $p < .001$, $\eta_p^2 = .77$; $F_2(1,84) = 99.96$, $MSE = 1444.04$, $p < .001$, $\eta_p^2 = .54$; errors: $F_1(1,27) = 4.25$, $MSE = .121$, $p < .05$, $\eta_p^2 = .14$; $F_2(1,84) = 9.29$, $MSE = .06$, $p < .01$, $\eta_p^2 = .10$). The main effect of Transparency in both RT and error analyses indicated that transparent particle verbs (551 ms, 1.95% errors) were responded to faster and with fewer errors than opaque particle verbs (563 ms, 4.22% errors), although this effect did not reach significance in the RT analysis by items (|RTs: $F_1(1,27) = 6.62$, $MSE = 1193.03$, $p < .05$, $\eta_p^2 = .20$; $F_2(1,84) = 3.37$, $MSE = 2753.08$, $p = .07$, $\eta_p^2 = .04$; errors: $F_1(1,27) = 9.46$, $MSE = .096$, $p < .01$, $\eta_p^2 = .26$; $F_2(1,84) = 5.67$, $MSE = .121$, $p < .05$, $\eta_p^2 = .06$). As we are primarily interested in priming effects (and not between-word main effects), this main effect of Transparency will not be discussed further. None of the other effects or interactions reached significance ($F_s < 1.39$, $p_s > .25$).

To find out whether individual differences in spelling or vocabulary abilities influenced the priming effect, we analysed the results for the spelling and vocabulary tests as described for Experiment 1. No indication was found that individual differences in these domains influenced the priming effect ($p_s > .10$; see Appendix C).

In this experiment, the roles of complex and simple verbs as primes and targets were reversed relative to Experiment 1. The results of Experiment 2 fully replicate the results of Experiment 1: The recognition of all (complex) targets was primed to the same degree by their stem, regardless of transparency and motor-relatedness. The replication of the overall morphological priming effect, not modulated by semantic transparency or motor-relatedness, gives further support to the hypothesis that transparent and opaque derivations are similar in terms of constituent priming effects in a language with a derivationally rich system such as Dutch.

A comparison of the results of Experiment 1 and 2 also suggests that prime-target order in constituent priming

Table 6. Experiment 2: Mean reaction times and error percentages.

			Related	Unrelated	Priming
Motor	Transparent	RT (in ms)	522 (81)	574 (85)	52
		Errors (in %)	1.30 (3.24)	2.92 (6.09)	1.62
	Opaque	RT (in ms)	530 (91)	591 (98)	61
		Errors (in %)	3.90 (6.27)	5.19 (6.74)	1.30
Non-motor	Transparent	RT (in ms)	523 (96)	584 (95)	61
		Errors (in %)	.65 (2.38)	2.92 (4.32)	2.27
	Opaque	RT (in ms)	540 (97)	589 (99)	49
		Errors (in %)	2.92 (4.98)	4.87 (7.21)	1.95
Mean		RT (in ms)	529 (91)	584 (93)	55
		Errors (in %)	2.19 (4.61)	3.98 (6.20)	1.79

Note: Standard deviations in parentheses.

(derivation-stem vs. stem-derivation) does not significantly affect priming: Our RT results show overall priming effects of similar size in both experiments (derivation – stem: 57 ms, $\eta^2_{p1} = .86$; $\eta^2_{p2} = .59$; stem – derivation: 56 ms, $\eta^2_{p1} = .77$; $\eta^2_{p2} = .54$). These findings are similar to those of the few studies comparing the two prime-target orders (Marslen-Wilson et al., 1994; Marslen-Wilson & Zhou, 1999). The error analyses also show similar results in the two constituent priming experiments: an overall morphological priming effect in both Experiment 1 and 2. In general, we can conclude that the two orders give highly similar results.

In Experiment 3, we tested whether these results also hold when a different priming type is used. For this, we proceed with semantic stem priming, i.e. particle verb targets are preceded by primes that are either semantically related or unrelated to the target verbs' stem. As mentioned in the Introduction, Zwitserlood's (1994) findings suggest that transparency may play a role in semantic stem priming, as opposed to constituent priming.

Experiment 3: semantic stem priming

Method

Participants

Thirty-one Dutch native speakers from the same population as in Experiments 1 and 2 participated. After exclusion (see below), 28 participants (21 female; 23 right-handed) remained. Their mean age was 21.8 years (SD: 3.4; range: 18–30). They all signed a written consent form in accordance with the Declaration of Helsinki. None of the participants had participated in Experiment 1 or 2.

Materials

Targets and primes. The targets used for this experiment were the same as those used for Experiment 2. Each complex verb target was paired with a related and an unrelated prime (see Table 7 for examples and

Appendix A for a list of all experimental stimuli). Related primes were simple words semantically related to the stem of the complex verbs. This implies that the primes were also semantically related to the transparent complex verbs as a whole, but not to the opaque complex verbs as a whole (e.g. *pen* “pen” with transparent target *opschrijven* “to write down”; *studeren* “to study” with opaque target *toekennen* “to award” (stem *kennen* “to know”). As the example with *opschrijven* shows, sometimes simple nouns rather than simple verbs were selected. This was done to make sure that the related primes were as closely related to the targets as possible. The corresponding unrelated primes were simple nouns or verbs unrelated to the complex verbs or their stem (e.g. *wiel* “wheel” with target *opschrijven* “to write down”; *ademen* “to breathe” with target *toekennen* “to award”). Relatedness was determined on the basis of a semantic relatedness web-based rating study. For this study, a pool of word pairs was used consisting of complex verbs and semantically related and unrelated simple words. The complex verbs consisted of the particle verbs presented in the previous two experiments, whereas the simple words were selected on the basis of the web-based *Dutch Word Association Database* (De Deyne, 2010) and the web-based Dutch synonym dictionary *Synoniemen-net* (Van Kol, 2006–2014). Forty-two native speakers of Dutch (who did not participate in the main experiment or the other rating studies) were presented with these

Table 7. Experiment 3: Design and examples of stimuli.

		Target	Related prime	Unrelated prime
Motor	Transparent	opschrijven (to write down)	pen (pen)	wiel (wheel)
	Opaque	uitvreten (to be up to)	smullen (to feast on)	wieden (to weed)
Non-motor	Transparent	nadenken (to reflect, consider)	piekeren (to brood)	wapperen (to flap, flutter)
	Opaque	toekennen (to award)	studeren (to study)	ademen (to breathe)

word pairs, and asked to judge how strongly related their meanings were (on a scale of 1 “no relation at all” to 5 “very strong relation”). They also had to indicate whether they thought the target consisted of different parts. If so, they were asked to judge how strongly related the meanings of the prime and the target stem were (again on a scale of 1–5).

On the basis of this pre-test, 88 semantically related and 88 semantically unrelated primes were chosen (see Table 8 for prime characteristics). Compared to the unrelated primes, the related primes were judged to be significantly more semantically related to the transparent complex targets ($ps < .001$) and to the target stems ($ps < .001$). In contrast, no significant difference was found between related and unrelated primes in terms of semantic relatedness to the opaque complex targets ($ps > .10$). In addition, related and unrelated primes were matched in terms of frequency (ln of Celex lemma frequency: $ps > .36$), length (number of letters: $ps > .13$) and word class: Each pair of related and unrelated primes associated with a specific target was of the same word class, either noun or verb.

Fillers. As in Experiments 1 and 2, 88 simple verbs were selected as filler targets to distract attention from the complex verb targets. Half of the filler targets (44) were combined with a semantically related filler prime (e.g. *naderen* “to approach” with target *komen* “to come”), the other half (44) with an unrelated filler prime (e.g. *bakken* “to bake” with target *volgen* “to follow”). The same proportion of nouns and verbs was used for filler primes and experimental primes.⁴

Pseudo-words. The pseudo-words used in this experiment were the same as those used in Experiment 2. Each pseudo-word target was paired with a morphologically simple noun or verb prime. Nouns and verbs were selected in the same proportion as for the filler primes and the experimental primes.

Lists. Four lists were created according to the same criteria as those used in Experiments 1 and 2.

Procedure

The same procedure was used as in Experiments 1 and 2, both for the main experiment and for the spelling and vocabulary tests.

Results and discussion

Three participants were excluded from the analyses: Two because their mean error percentage or RT to pseudo-words and/or words was more than three standard deviations above the mean, and one because she noticed the semantic relationship between the related primes and the stems of the opaque particle verbs. One item (*opfokken* “to work up”) was excluded from the analyses because its mean error percentage was more than three standard deviations above the mean. In the reaction time analyses, incorrectly answered trials (3.6%) were excluded, as were trials with an RT more than two standard deviations away from both a given item’s mean and a given participant’s mean for experimental targets (1.8%). Again, error rates were arcsine-transformed prior to analysis.

Mean RTs to words and pseudo-words were 554 ms (SD 71 ms) and 637 ms (SD 80 ms), respectively. Participants made an average of 4.22% errors to words (SD 3.37%) and of 5.11% errors to pseudo-words (SD 3.59%).

In this semantic stem priming experiment, a different pattern of RT results to complex words emerged than in the previous experiments (see Table 9 for an overview of mean RTs). Descriptively, the largest priming effect was found for transparent motor verbs. A repeated-measures ANOVA with Transparency, Motor-Relatedness, and Prime Relatedness as factors revealed significant main effects of Transparency (transparent: 540 ms, opaque: 559 ms; $F_1(1,27) = 36.50$, $MSE = 543.23$, $p < .001$, $\eta_p^2 = 0.57$; $F_2(1,83) =$

Table 8. Experiment 3: Characteristics of primes.

	Related primes				Unrelated primes			
	Length	Frequency	Rated semantic relatedness target	Rated semantic relatedness target stem	Length	Frequency	Rated semantic relatedness target	Rated semantic relatedness target stem
Motor transparent	6.05 (1.89)	7.17 (1.66)	4.05 (.33)	4.32 (.49)	5.77 (1.54)	7.20 (1.74)	1.32 (.29)	1.32 (.32)
Motor opaque	5.55 (1.34)	6.94 (1.43)	1.44 (.29)	4.21 (.35)	5.59 (1.22)	6.95 (1.42)	1.29 (.31)	1.20 (.22)
Non-motor transparent	5.41 (1.53)	7.72 (1.95)	4.13 (.32)	4.28 (.37)	5.45 (1.74)	7.71 (2.01)	1.33 (.28)	1.37 (.32)
Non-motor opaque	5.36 (1.43)	7.56 (1.37)	1.48 (.27)	4.15 (.36)	5.14 (1.32)	7.46 (1.40)	1.36 (.29)	1.34 (.42)

Notes: Means of characteristics shown (standard deviations in parentheses). Length: in letters. Frequency: ln-transformed Celex frequency counts. Semantic relatedness rating: on a scale of 1–5, with 1 = low degree and 5 = high degree of semantic relatedness.

6.92, $MSE = 2380.94$, $p = .01$, $\eta_p^2 = .08$) and Prime Relatedness (related: 543 ms, unrelated: 556 ms; $F_1(1,27) = 5.17$, $MSE = 1839.22$, $p < .05$, $\eta_p^2 = .16$; $F_2(1,83) = 6.35$, $MSE = 1262.01$, $p < .05$, $\eta_p^2 = .07$). These effects were modulated by an interaction between Transparency and Prime Relatedness, which was, however, significant only in the participants analysis ($F_1(1,27) = 4.27$, $MSE = 921.40$, $p < .05$, $\eta_p^2 = .14$; $F_2(1,83) = 2.12$, $MSE = 1262.01$, $p = .15$, $\eta_p^2 = .02$), and by a significant triple interaction between Transparency, Prime Relatedness and Motor-Relatedness ($F_1(1,27) = 11.61$, $MSE = 766.43$, $p < .01$, $\eta_p^2 = .30$; $F_2(1,83) = 6.14$, $MSE = 1262.01$, $p < .05$, $\eta_p^2 = .07$). None of the other effects or interactions were significant ($F_s < 1.96$, $p_s > .17$).

Follow-up analyses on motor and non-motor verbs separately revealed a significant main effect of Transparency for both types of verbs, although for motor verbs this was only significant in the participants analysis (motor verbs: transparent: 544 ms, opaque: 556 ms; $F_1(1,27) = 5.80$, $MSE = 726.90$, $p < .05$, $\eta_p^2 = .18$; $F_2(1,42) = 2.49$, $MSE = 1679.38$, $p = .12$, $\eta_p^2 = .06$; non-motor verbs: transparent: 537 ms, opaque: 563 ms; $F_1(1,27) = 17.25$, $MSE = 1043.84$, $p < .001$, $\eta_p^2 = .39$; $F_2(1,41) = 4.38$, $MSE = 3099.62$, $p < .05$, $\eta_p^2 = .10$). For non-motor verbs, no other significant effects or interactions were found ($F_s < 2.30$, $p_s > .13$). In contrast, the analysis on motor verbs further revealed a significant main effect of Prime Relatedness (related: 542 ms, unrelated: 557 ms; $F_1(1,27) = 6.14$, $MSE = 965.86$, $p < .05$, $\eta_p^2 = .19$; $F_2(1,42) = 4.31$, $MSE = 1153.23$, $p < .05$, $\eta_p^2 = .09$) and a significant Transparency by Prime Relatedness interaction ($F_1(1,27) = 18.61$, $MSE = 662.83$, $p < .001$, $\eta_p^2 = .41$; $F_2(1,42) = 8.57$, $MSE = 1153.23$, $p < .01$, $\eta_p^2 = .17$). Paired t -tests showed that there was a significant priming effect for transparent motor verbs (35 ms; $p_1 < .001$; $p_2 < .01$), which was not present for opaque motor verbs (–6 ms; $p_s > .46$).

Table 9. Experiment 3: Mean reaction times and error percentages.

			Related	Unrelated	Priming
Motor	Transparent	RT (in ms)	526 (79)	561 (80)	35
		Errors (in %)	1.30 (4.08)	2.60 (5.45)	1.30
	Opaque	RT (in ms)	559 (83)	553 (75)	–6
		Errors (in %)	3.57 (5.72)	3.57 (6.70)	.00
Non-motor	Transparent	RT (in ms)	534 (61)	541 (70)	7
		Errors (in %)	3.25 (5.08)	5.52 (6.23)	2.27
	Opaque	RT (in ms)	555 (75)	571 (84)	16
		Errors (in %)	4.45 (7.22)	4.71 (8.12)	.26
Mean	RT (in ms)	543 (75)	556 (77)	13	
	Errors (in %)	3.14 (5.68)	4.10 (6.70)	.96	

Note: Standard deviations in parentheses.

The analysis of the error data (see Table 9 for an overview) only revealed a main effect of Motor-Relatedness ($F_1(1,27) = 7.72$, $MSE = .08$, $p < .01$, $\eta_p^2 = .22$; $F_2(1,83) = 4.65$, $MSE = .126$, $p < .05$, $\eta_p^2 = .05$). More errors were made to non-motor verbs (4.5%) than to motor verbs (2.8%). None of the other effects or interactions were significant ($F_s < 2.65$, $p_s > .10$).

The linear regression analyses with Spelling Rate and Vocabulary Rate as independent variables again showed no evidence of an effect of these variables on the priming effect ($p_s > .40$; see Appendix D). Thus, in contrast with Andrews and Lo's (2013) results, none of our experiments gave any indication that individual differences in spelling and vocabulary abilities influenced the results. It is unclear whether the difference between our and Andrews and Lo's (2013) results is due to differences in the priming paradigm (unmasked vs. masked priming, respectively), differences between the participant groups studied, or some other reason.

To summarise, Experiment 3 showed that, with a semantic stem priming paradigm, the priming effect was modulated by both semantic transparency and motor-relatedness: Only transparent motor (complex) verbs showed semantic stem priming. This contrasts with the overall morphological priming effect found with constituent priming in Experiments 1 and 2.

The overall morphological priming effects found in the constituent priming experiments (Experiments 1 and 2) contrast with the results found in the semantic stem priming experiment (Experiment 3): a priming effect modulated by both semantic transparency and motor-relatedness. The combined results suggest that not only transparency, but also priming type and motor-relatedness may play a role in the processing of Dutch particle verbs. This will be explored in more detail in the General Discussion.

General discussion

In this study, three behavioural overt priming experiments were used to investigate the influence of type of morphological priming (constituent vs. semantic stem) and motor-relatedness on the processing of Dutch particle verbs. In Experiment 1, with constituent priming, transparent and opaque, motor and non-motor particle verbs were followed by their stems as targets; in Experiment 2, the reverse prime-target order was used. The same particle verbs were used in the semantic stem experiment (Experiment 3), but this time the primes were simple words semantically related to their stem. Results show an overall priming effect in Experiment 1 which was not modulated by transparency or motor-relatedness. Experiment 2 provided a full

replication of this constituent priming pattern with the reverse prime-target order, showing that prime-target order does not change results for constituent priming. A different pattern was obtained in Experiment 3 with semantic stem priming. The priming effect in this experiment was found for transparent motor verbs only. Thus, not only semantic transparency, but also motor-relatedness seems to be able to influence the processing of Dutch particle verbs, at least in the context of semantic stem priming. The type of morphological priming seems to determine whether or not semantic transparency and motor-relatedness can exert an influence. We will address these factors below.

Type of morphological priming

One key result of our study is the fact that different patterns of priming were found for constituent priming and semantic stem priming. Whereas we observed robust priming effects in all conditions regardless of transparency and motor-relatedness in constituent priming, priming effects were restricted to transparent motor verbs in semantic stem priming. Our results with regard to transparency are in line with several previous overt priming studies on Dutch and German using one of these priming types (Lüttmann et al., 2011; Smolka et al., 2009, 2014; Zwitserlood et al., 2005; see also Smolka et al., 2015). However, none of these studies included both morphological priming techniques (constituent priming and semantic stem priming). The only previous study comparing both techniques, albeit for compounds (Zwitserlood, 1994), did not do so systematically (i.e. with the same materials and in a balanced design, see Introduction), as the present study did. By systematically comparing the two types of morphological priming, we can exclude the possibility that the different results for the different priming methods obtained in the previous studies were due to differences in the materials or other factors. Rather, taken together, our results and the previous findings consistently show that the particular priming technique itself affects whether and for which words (e.g. transparent vs. opaque words) morphological priming is observed. Thus, morphological priming can no longer be seen as a “neutral observation method” of morphological processing; instead, it appears to influence precisely those processes that it is meant to observe.

These findings raise the question in which way the type of priming influences morphological processing. A possible explanation is that constituent priming may direct the reader’s attention towards the morphological structure of complex words. Thus, it may lead to increased activation of the morphologically decomposed

representations of these words, compared to their whole-word representations. As a result, facilitation occurs for all morphologically complex words. In contrast, a semantic stem priming context may lead to an increased focus on semantic relations between primes and complex targets. Therefore, deeper conceptual processing may occur, possibly leading to an increased influence of semantic variables in the processing of morphologically complex words. As a result, facilitation of a complex word depends on its transparency and motor-relatedness.

As far as we can tell, none of the existing models of morphological processing provides a direct explanation for the difference between the types of priming. However, one could extrapolate some models such that they might provide such an explanation. For example, in terms of parallel dual-route (Baayen & Schreuder, 1999; Schreuder & Baayen, 1995) and multiple-route (Kuperman, Bertram, & Baayen, 2010; Kuperman, Schreuder, Bertram, & Baayen, 2009) models – with a holistic processing route and a decompositional route running in parallel –, the type of priming may determine which of the two processing routes is faster or more dominant. In a constituent priming context, the focus on morphological structure may shift the balance between the two routes in favour of the decompositional route. In a semantic stem priming context, the decompositional route plays less of a role and the holistic processing route may become more important. In the dual- and multiple-route models, the balance between the two routes is dependent on word (constituent) characteristics (length, frequency) and/or morphological family size (i.e. the paradigmatic context of a morphologically complex word in the mental lexicon). However, what is not accounted for in these models is the influence of experimental context, such as type of morphological priming. To be compatible with our results, this variable should be included in the models.

Another model that may be relevant to our results is the frequency-based model for the processing of inflections and derivations (Smolka, Zwitserlood, & Rösler, 2007; Smolka et al., 2014). In contrast with the dual-route models, it contains a single processing route for semantically transparent and opaque derivations, rather than two or more parallel routes. For both transparent and opaque derivations, initial morpho-orthographic segmentation is followed by the activation of morphological constituents at the lexical level. Unlike the dual-route models, there are no whole-word representations at this level. Instead, whole-word representations are relegated to the “conceptual” level, which contains the semantic representations of morphological constituents and of whole words (in contrast with the

“semantic/syntactic” level of dual-route models, which contains representations of semantic and syntactic aspects of words). Both the activation of individual constituents and the joint activation of several constituents lead to the activation of the corresponding concepts at the conceptual level. For instance, for an opaque derivation like *uitvreten*, the activated concepts will be “out” (*uit*) and “to devour” (*vreten*), as well as the meaning of the whole word, i.e. “to be up to”. Which concept is selected depends on frequency: the concept that is most frequently activated upon co-activation of the constituents involved is selected.

This model can explain the constituent priming effects found for both transparent and opaque derivations in morphologically rich languages such as German (e.g. Smolka et al., 2014) and Dutch (e.g. this study). It is, however, not very clear how the frequency-based model would handle the results of our semantic stem priming experiment. In our interpretation of the model, there is no clear explanation for the difference in priming effects between transparent and opaque derivations. Also, the role of motor-relatedness seems, at this point, difficult to integrate in the model. It is conceivable, though, that the model could be developed further to account for our results.

Smolka and colleagues (2007, 2009, 2014, 2015) do, in our view, rightly point out that type of language may also have to be taken into account to explain the whole range of previous behavioural priming results. As mentioned before, numerous constituent priming studies in morphologically poor languages such as English reported differential priming effects for semantically transparent and opaque derivations (English: Feldman & Soltano, 1999; Feldman et al., 2004; Gonnerman et al., 2007; Marslen-Wilson et al., 1994; Rastle et al., 2000; French: Longtin et al., 2003)⁵ as opposed to the overall priming effects in studies on derivations in German, a morphologically rich language (Lüttmann et al., 2011; Smolka et al., 2009, 2014; see also Smolka et al., 2015; but see Feldman, Barac-Cikoja, & Kostić, 2002). Possibly, semantic word characteristics such as transparency can only exert their influence in constituent priming in morphologically poor languages, as opposed to morphologically rich languages. Thus, in German and Dutch, two languages with a similarly rich derivational system, readers might generally use more decomposition-based strategies for derivations, so that constituent priming leads to an overall morphological priming effect regardless of transparency. In contrast, English has a relatively poor derivational system (Dressler, 2005; Duncan et al., 2009; Haman et al., 2009), so that holistic processing might be favoured more often. Thus, constituent priming may not be enough to always induce decomposition: it

does so only for transparent derivations (but see Bozic et al., 2007). This hypothesis clearly asks for studies like the present one, but then on languages whose derivational system is less rich than Dutch or German.

The constituent priming paradigm was tested in two orders of stem and derivation: derivation – stem and stem – derivation, using the same experimental stimuli (derived verbs). Both orders have been used before in the overt priming literature. However, the two orders have been compared for the same item set only once (Marslen-Wilson et al., 1994), and this was done in English, which is morphologically less rich than Dutch. Theoretically, the stem – derivation order could increase the priming effect by focusing attention more on the morphological structure of the complex word than the reverse order (but see Kirkici & Clahsen, 2013, for an opposing view). Our RT results show no difference in priming effects between the two prime – target orders: we found overall priming effects of a similar size in the two constituent priming experiments (derivation – stem: 57 ms, $\eta^2_{p1} = .86$, $\eta^2_{p2} = .59$; stem – derivation: 56 ms, $\eta^2_{p1} = .77$, $\eta^2_{p2} = .54$). In an additional analysis of Experiments 1 and 2 together, no interactions were found between Prime Relatedness and Experiment ($F_s < 1.72$, $p_s > .19$). These findings are similar to those of the studies comparing the two prime – target orders in English (Marslen-Wilson et al., 1994; Marslen-Wilson & Zhou, 1999). The error analyses of our data did suggest that the priming effect was slightly larger for the derivation – stem order than for the reverse order (stem – derivation: 1.79%, $\eta^2_{p1} = .16$, $\eta^2_{p2} = .08$; derivation – stem: 3.86%, $\eta^2_{p1} = .40$, $\eta^2_{p2} = .20$). However, the Prime Relatedness by Experiment interaction was only significant in the item analysis, and the effect size was very small ($F_1(1,54) = 2.93$, $MSE = .004$, $p = .093$, $\eta^2_p = .05$; $F_2(1,81) = 4.75$, $MSE = .003$, $p < .05$, $\eta^2_p = .06$). Thus, the suggestion that the stem – derivation order may lead to increased priming is not supported, whereas the claim that it leads to reduced priming is only weakly supported, and only for the error results, not for the RT results. In general, we can conclude that the two directionalities give highly similar results.

To summarise, our results show that overt priming effects are not only determined by word characteristics such as the frequency or transparency of derivations, but also by contextual factors such as the type of morphological priming, whereas prime – target order does not or hardly influence the results for constituent priming. The type of morphological priming (constituent priming vs. semantic stem priming) may influence which route (decompositional or holistic) and/or which level of representation (morphemic or whole-word) receives more weight in the processing of derivations. Thus, the

type of overt priming seems to have an effect on the way derivations are processed, i.e. whether or not they are decomposed. This contrasts with the traditional assumption that word recognition processes – including morphological processes – are reflected in, but not influenced by different methods of priming.

Motor-relatedness

Our results show that priming effects are also influenced by motor-relatedness. In our semantic stem priming experiment, the priming effect was modulated by both semantic transparency and motor-relatedness: Only transparent motor verbs were primed by words semantically related to their stems, as opposed to transparent non-motor verbs or opaque verbs. A modulation of the priming effect by transparency has been found in previous overt priming studies (see above), but a modulation by motor-relatedness has, to our knowledge, not been reported before (but see Feldman, Basnight-Brown, & Pastizzo, 2006, for a modulation of the constituent priming effect by concreteness).

The priming effect for transparent motor verbs indicates that, in a semantic stem priming context, the stem of a transparent verb is more easily separated from its particle if it is motor-related. The influence of motor-relatedness points towards a language embodiment account, and may be due to an increased emphasis on semantic relations in semantic stem priming. In such a context, deeper conceptual processing may occur. According to Barsalou, Santos, Simmons, and Wilson (2008), deep conceptual processing involves simulation, i.e. activation in the brain's sensory and motor systems to simulate the states referred to by the word form. If deep conceptual processing indeed involves simulation, this might explain why priming was modulated not only by semantic transparency, but also by motor-relatedness: Motor and non-motor verbs will differ in terms of simulation.

Note that motor verbs are also more imageable, and/or more concrete, than non-motor verbs. It could thus be the case that imageability (or a combination of imageability and concreteness) was (part of) the driving force behind our observed effects of motor-relatedness (see Prado & Ullman, 2009, for the role of imageability on storage vs. computation of complex forms). Obviously, these factors are difficult to disentangle.

We can explore the role of motor-relatedness in more detail in the context of the parallel dual-route (Baayen & Schreuder, 1999; Schreuder & Baayen, 1995) and multiple-route models (Kuperman et al., 2009, 2010). If there is an increased focus on semantic relations in the semantic stem priming paradigm, the obvious semantic

relation between transparent verbs and their stem may lead to faster recognition of the morphological structure of transparent verbs compared to opaque verbs. As a result, the decompositional route may be facilitated in transparent verbs as compared to opaque verbs. However, transparency may not be enough to tip the balance in favour of decomposition. This is where motor-relatedness comes in. Words associated with a higher degree of motor-related content are supposed to be easier to simulate and/or evoke more semantic activation than words less grounded in bodily experience (Bennett et al., 2011; Kuperman, 2013; Siakaluk, Pexman, Aguilera, et al., 2008; Siakaluk, Pexman, Sears, et al., 2008; Sidhu et al., 2014). Within the parallel dual-route model, more semantic activation could lead to more activation feedback from the semantic nodes (i.e. semantic representations) to the concept nodes (i.e. lexical representations). As a result, there would be more sustained activation of the stem when it is motor-related than when it is not motor-related. This may become especially apparent in a context which promotes deeper conceptual processing such as semantic stem priming. In such a context, transparent verbs with a motor-related stem may receive an advantage not only because of their transparency, but also because of the motor-relatedness of their stem: Their stem may get more sustained activation than non-motor-related stems of transparent verbs. This may give the decompositional route enough of a boost to outperform the holistic route. To recapitulate, transparent motor particle verbs would receive an advantage in a semantic stem priming context, because their transparency increases the speed with which the relation between the particle verbs and their stem is recognised, and their motor-relatedness leads to more sustained activation of the stem because motor-related stems evoke more semantic activation.

The present results, indicating that motor-relatedness may modulate priming effects in derivations, raise the question why Kuperman (2013) did not find any influence of the degrees of sensory experience rating (SER) and body-object interaction (BOI) of compound constituents on the lexical decision times of these compounds as a whole. His results were interpreted as arguing against the dual- and multiple-route models: If the decompositional route was used as regularly as proposed by these models, one would have expected to find an influence of the degrees of SER and BOI of the constituents, it was argued. One possibility is that the difference in stimuli (derived verbs in our experiments and compounds in Kuperman, 2013) led to the difference in results because compounds may be less likely to be decomposed than derived verbs. However, this seems

unlikely in light of the many studies showing that transparent and/or opaque compounds are decomposed (Duñabeitia, Laka, Perea, & Carreiras, 2009; Gagné & Spalding, 2004; Ji, Gagné, & Spalding, 2011; Jia, Wang, Zhang, & Zhang, 2013; Koester, Gunter, & Wagner, 2007; Kuperman et al., 2009; Lemhöfer, Koester, & Schreuder, 2011; Pollatsek, Hyönä, & Bertram, 2000; Sandra, 1990).

Another possible reason for the difference between our and Kuperman's (2013) results is the difference in paradigm used: primed versus unprimed lexical decision. It seems to be the case that different paradigms (e.g. overt priming vs. no priming, see Bozic et al., 2007 vs. Bozic, Tyler, Su, Wingfield, & Marslen-Wilson, 2013; Clahsen, Sonnenstuhl, & Blevins, 2003; constituent priming vs. semantic stem priming, see above), and even variations within one paradigm (Ji et al., 2011), produce different results for complex words.

To summarise, motor-relatedness was found to modulate the priming effect in a semantic stem priming context, but not in constituent priming. Thus, in semantic stem priming, transparency alone is not enough to elicit a priming effect: Facilitation only occurred for transparent verbs with a motor-related stem. This may be due to more sustained activation of motor-related stems because of their ease of simulation and/or higher degree of semantic activation.

Conclusions

Whether or not particle verbs are decomposed seems to depend on a complex interplay of factors influencing whether or not the morphological structure of these verbs is recognised. Our results suggest that, in a morphologically rich language, constituent priming directs the attention to the morphological structure of particle verbs, such that decomposition becomes the dominant route. As a result, other factors, such as transparency and motor-relatedness, are irrelevant in this context: All particle verbs are decomposed, independent of their transparency or their motor-relatedness. In a semantic stem priming context, however, the focus is less strongly on the morphological structure of particle verbs, allowing transparency and motor-relatedness to exert their influence. Thus, decomposition will only occur if particle verbs are both transparent and motor-related – both factors increasing the likelihood that the morphological structure of particle verbs is recognised.

The fact that our results depended on *which* version of the morphological priming paradigm was used (constituent vs. semantic stem priming) suggests that these different methods are not purely *measuring* morphological processing. Rather, it seems that the priming method

influences the way in which readers process the derived verbs.

Furthermore, we are the first to observe a modulating effect of motor-relatedness on morphological priming. This effect can be linked to embodied cognition theory: The priming effect for transparent motor verbs may be due to deeper conceptual processing in the semantic stem priming type, allowing the increased semantic activation and/or ease of simulation of the stems of these verbs to exert their influence.

Notes

1. Particle verb frequency should be treated with caution, as the Celex frequency counts of particle verbs are only based on the frequency of these verbs when used as a whole, not including their frequency when separated from their particles. However, no better count is available.
2. Primes and targets were presented at different lines to avoid visual aftereffects that might occur due to form overlap between prime and target.
3. Due to the fact that filler trials mimicked the characteristics of critical trials, they had to be slightly adapted compared to Experiment 1. The same was true for the pseudo-word trials.
4. Due to the fact that filler trials mimicked the characteristics of critical trials, they had to be adapted compared to Experiment 1. The same was true for the primes in pseudo-word trials.
5. Some of the studies referred to here also present the results of masked priming experiments. As the present study only deals with overt priming, we are only concerned with their overt priming results here.

Disclosure statement

No potential conflict of interest was reported by the authors.

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