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Reading morphologically complex words in German: the case of particle and prefixed verbs

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ABSTRACT

German verb stems may be combined with a particle or a prefix, forming particle and prefixed verbs, respectively. Both types of verbs are morphologically complex, yet particles are free morphemes, which are routinely separated from their stem and can stand alone in a sentence, whereas prefixes are bound morphemes, which are attached to their stem and cannot stand alone in a sentence. Morphologically complex words are thought to be segmented into their constituent morphemes during reading. On this assumption, we took advantage of the separability feature of the constituent morphemes of particle verbs to investigate how the segmentation process occurs in skilled reading. Thirty German adults participated in a sentence-reading task that employed the eye-contingent boundary paradigm in eye-tracking. We observed no differences in the processing of particle and prefixed verbs, which suggests that idiosyncratic linguistic characteristics do not modulate the way morphologically complex words are segmented in skilled reading.

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Introduction

In his essay titled “The Awful German Language”, Mark Twain (1880) wrote:


The Germans have another kind of parenthesis, which they make by splitting a verb in two and putting half of it at the beginning of an exciting chapter and the other half at the end of it. Can any one conceive of anything more confusing than that? These things are called ‘separable verbs.’ The German grammar is blistered all over with separable verbs; and the wider the two portions of one of them are spread apart, the better the author of the crime is pleased with his performance.

Separable verbs, most commonly referred to in the literature as particle verbs, are unique to Germanic languages.¹ Their most prominent feature is the separability of their constituent parts, which is clearly illustrated in the following sentence: Maria **sieht** nach der langen Autofahrt von München, wo sie beruflich zu tun hatte, sehr müde und erschöpft **aus** (=After her long drive from Munich, where she had job-related stuff to do, Maria **looks** very tired and exhausted). In the above sentence, the particle verb **aussehen** is segmented into two parts (**aus + sieht** – 3rd person singular in present tense). Critically, the particle **aus**, which defines the

meaning of the verb stem **sehen**, appears in sentence-final position, several words after the stem.

Particles may occur in three different positions relative to their base verb: (a) immediately before the verb stem in infinitive forms, which are typical in auxiliary + verb constructions, as in “Ich will heute abend gut **aussehen**”. (= I want to look good tonight); (b) separated by *ge-* in regular past participle forms, as in “Du hast neulich schlimm **ausgesehen**”. (= You looked bad the other day), or by *zu* in infinitive clauses, as in “Ich mag es, gut **auszusehen**”. (= I like to look good); (c) after the verb stem in phrase- or sentence-final position, as in “Du siehst gut **aus**”. (= You look good). Particle verbs are morphologically structured, just like prefixed verbs (Olsen, 1996). In fact, both particle and prefixed verbs consist of a verb stem (e.g. *sehen*) and either a particle (e.g. *aus-*) or a prefix (e.g. *be-*), forming particle verbs such as *aussehen* (= to look like, appear) and prefixed verbs such as *besehen* (= to inspect, have a look at). However, while particles are free morphemes, which can function as prepositions, adverbs, or adjectives, and can therefore stand alone in a sentence, prefixes are bound morphemes, which are always attached to the stem and cannot stand alone in a sentence. Hence,

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the main difference between particle and prefixed verbs is that the constituent morphemes of the former, but not of the latter, are routinely and obligatorily separated from each other in certain syntactic constructions.²

Almost every German verb can be combined with a particle or a prefix. In fact, it is difficult to find German base verbs with no family of derived particle or prefixed verbs. Verbs with large families may well have up to 150 derived forms (Smolka et al., 2014). Hence, both particles and prefixed verbs are very productive. The productivity of particle verbs is nicely illustrated in the following studies. Felfe (2012) presented participants with sentences from a corpus and asked them to indicate whether they recognised certain verbs in these sentences. All participants except one confirmed that they did not recognise the particle verb *anschlafen* (an + schlafen, “to start sleeping”), yet they could all figure out its possible meaning. Similarly, Springorum et al. (2013) created novel particle verbs and asked participants to associate a meaning to them, as well as to construct sentences using these novel verbs. Not only participants could effortlessly do this task, but some of them also agreed on the meaning they attributed to the novel verbs.

Processing differences between particle and prefixed verbs

A few studies have investigated whether particle and prefixed verbs are processed differently. The methodology and materials used, as well as the way in which the analyses were conducted vary across studies. Below we briefly describe these studies and we outline their main findings.

In a study conducted in Dutch (Schreuder et al., 1990), a priming paradigm was used in a reading aloud task that involved two experiments: one containing particle verbs and another containing prefixed verbs. Three priming conditions were used in each experiment: no priming, priming that involved either the particle or the prefix of the verb appearing on the screen 60 ms before the whole word, and priming that involved the stem appearing on the screen 60 ms before the whole word. Nouns beginning with the same letter strings as the particle or the prefixed verbs were used as control items in each experiment. Analyses of response latencies revealed priming effects for particle verbs, but not for prefixed verbs, suggesting faster processing of the former compared to the latter. It is worth noting, however, that this study had certain limitations. Firstly, some of the control items were morphologically complex words (note that a full list of materials is not included in the paper, yet the examples of control items that were provided corresponded to complex

words). As a result, potential differences between prefixed and control items may have been difficult to detect. Secondly, the interaction between verb type (particle vs. prefixed) and prime condition was not statistically tested, so it is unclear whether particle and prefixed verbs were indeed processed differently. Therefore, the findings from this study do not provide particularly strong evidence for processing differences between particle and prefixed verbs.

In a study conducted in German, the impact of derived verbs on the production and recognition of morphologically-related simple verbs was investigated using a production and a comprehension task, respectively (Lüttmann et al., 2011). In particular, target verbs (e.g. *zählen*, “to count”) were primed by morphologically related verbs that were either semantically transparent (e.g. *verzählen*, “to miscount”) or semantically opaque (e.g. *erzählen*, “to tell”), semantically related (e.g. *rechnen*, “to calculate”), and phonologically related (e.g. *zähmen*, “to tame”). The results revealed that morphologically-related complex verbs yielded overall faster picture naming latencies in the production task and faster lexical decision latencies in the comprehension task, thus indicating morphological influences on both production and comprehension. Semantically related verbs did not show any reliable effects. Critically, both particle and prefixed verbs were used in the morphological condition, thus allowing the authors to further examine whether potential differences in the processing of the two types of verbs has an impact on the production and comprehension of morphologically-related simple verbs. Results showed that in the comprehension task only, particle verbs facilitated decision latencies to the targets compared to prefixed verbs. It is worth noting, nevertheless, that particle and prefixed verbs were not matched on length and word frequency in that study, so the obtained effects could be attributed to factors other than processing differences between the two types of verbs.

Other relevant studies, one that involved auditory recognition of morphologically-complex words in Dutch (Schriefers et al., 1991), and another that investigated the influence of semantic transparency on the processing of German multi-morphemic verbs, including particle and prefixed verbs, using an overt cross-modal priming paradigm (Smolka et al., 2019), found no evidence that particle and prefixed verbs are processed differently. Taken together, empirical studies that specifically investigated whether particle and prefixed verbs are processed differently, do not provide strong evidence in favour of this idea. However, a potential limitation of these studies is that they only used experimental paradigms at the single-word level.

Morphological processing in reading

Investigating how particle and prefixed verbs are processed is particularly relevant for research on the role of morphology in language processing, especially in the reading domain. In general, there is consensus nowadays that morphologically complex words are segmented into their constituent morphemes, a process that is believed to enable access to their corresponding lexical representations, thus facilitating their recognition (Taft & Forster, 1975). Two issues are still under debate though in this research domain. The first concerns the *nature of the segmentation process*, with the debate focusing on whether it is indeed morphological/morpho-orthographic or semantic. The second concerns *how segmentation occurs*; in particular, one account postulates that the affix is stripped off (Taft & Forster, 1975), whereas according to a more recent account, the embedded stem is activated (Grainger & Beyersmann, 2017). Particle and prefixed verbs have been used in a handful of studies on visual and auditory word recognition to investigate the first issue, yet no studies have used these verbs so far to investigate the second issue. In the present study, we capitalise on the special feature that differentiates particle from prefixed verbs, that is, the separability of their constituent morphemes, to investigate the second issue, namely *how morphologically complex words are segmented in skilled reading*. However, given how closely related the two issues are, we outline the empirical evidence on both.

Nature of the segmentation process

The nature of the segmentation process has been investigated in a number of studies using the masked priming paradigm (e.g. Longtin et al., 2003; Rastle & Davis, 2008; Rastle et al., 2004). These studies found that target word recognition in the visual domain was facilitated not only when masked primes were morphologically and semantically related to their targets (e.g. *darkness-DARK*), but also, when they had a pseudo-morphological relationship with their targets (e.g. *corner-CORN*, where *corner* is not morphologically related to *corn*, yet it consists of an apparent stem and a pseudo-suffix). Critically, such facilitation was not obtained when primes and targets were orthographically related but had no pseudo-morphological relationship (e.g. *brothel-BROTH*, where *el* is not a suffix). These results provided support for the operation of a semantically-blind, morpho-orthographic segmentation process during visual word recognition. However, more recently, prime-target pairs with a pure orthographic similarity, such as *cornea-CORN*, were found to yield similar facilitation as prime-target pairs with a pseudo-morphological relationship, such as

corner-CORN (Milin et al., 2017). In addition, semantically related pairs were found to yield faster responses than pseudo-morphologically related pairs (Diependaele et al., 2009; Feldman et al., 2009). Related to this is also the finding that semantic effects either precede or emerge simultaneously with morphological effects during the time-course of visual word recognition (Schmidtke et al., 2017). As a result, the exact nature of the segmentation process that is at play during the recognition of morphologically complex words has been under debate.

Particle (e.g. *aufstehen*) and prefixed (e.g. *verstehen*) verbs can play a critical role in this debate, because in contrast to pseudo-derivations of the *corner-corn* type, these verbs are real morphological derivations of their base verb (i.e. *stehen*). Importantly, the meaning relatedness between particle and prefixed verbs and their corresponding base verb (i.e. stem) may vary from fully transparent to fully opaque. For example, the pair *aufstehen-stehen* (“stand up-stand”) has a semantically transparent relationship, whereas the pair *verstehen-stehen* (“understand-stand”) has a semantically opaque relationship. In addition, all prefixes and all particles can produce semantically transparent and semantically opaque derivations. Thus, particle and prefixed verbs prove to be an ideal case for determining the nature of the segmentation process. Accordingly, a series of studies conducted in both German and Dutch (e.g. Creemers et al., 2020; Smolka et al., 2014; 2019; Smolka et al., 2009) used such verbs, within cross-modal and intra-modal priming paradigms in the visual and auditory domain, to investigate this issue. The results from these studies consistently showed that prior presentation of morphologically complex verbs facilitated the recognition of their stems independently of their semantic transparency, thus offering support for pure morphological effects on word recognition.

How segmentation occurs

With regard to how the segmentation process occurs, affix-stripping has been a dominant account in the area of visual word recognition. According to this account, a mechanism identifies the affix in morphologically complex words and strips it off, thus facilitating the recognition of the associated stem (Taft & Forster, 1975). This account, however, has some difficulties in explaining effects of pseudo-affixation, as those obtained by the *corner-corn* type of items. An alternative approach, which has been recently put forward (Grainger & Beyersmann, 2017), posits that edge-aligned embedded stems (rather than affixes) are the units that trigger the segmentation process during visual word recognition. More specifically, the main

difference between affix-stripping and embedded stem activation is that the former requires setting-up a new type of representation for letter combinations that are never delimited by spaces (i.e. prefixes, suffixes), whereas the latter uses free-standing morphemes (i.e. stems) that can be mapped onto pre-existing whole-word representations, a process that is facilitated by the marking of word boundaries by spaces between words. Particles, just like stems, and in contrast to prefixes, are free-standing morphemes. On the assumption that their “free-standing” feature enables their mapping onto pre-existing whole-word representations, which then trigger the segmentation process, we would expect particle verbs to be processed differently than prefixed verbs. It is worth noting that in a recent study that involved both single-word and sentence reading (Mousikou & Schroeder, 2019), we offered support for the embedded stem activation account by showing that skilled readers of German process embedded stems early during word recognition, independently of whether the stems are combined with an affix or a non-morphological letter sequence.

More generally, in the present study, we seek to gain an insight into how language-specific properties may influence the morphological segmentation process. Testing this idea is theoretically important, as it allows us to examine whether idiosyncratic linguistic characteristics modulate more general reading processes (Frost, 2012; Perfetti, 2003), which is in turn critical for determining whether a theory of reading with universal principles can account for the observed reading phenomena in this research domain.

Single-word reading versus sentence reading

Tasks that involve single-word reading, such as reading aloud and lexical decision, are often questioned as measures of word recognition. This is because in the former task, many words can be read aloud sublexically via grapheme-to-phoneme correspondences, without necessarily being recognised, while decision-making processes in the latter task are thought to influence the cognitive processes underlying word recognition (see e.g. Andrews et al., 2004). Also, response latencies in single-word reading tasks are typically much longer than fixation times in normal word reading, as measured by eye-tracking techniques in sentence-reading tasks (400–600 ms vs. 200–250 ms). These timing differences are likely due to (additional) articulatory and decision-making processes, in reading aloud and lexical decision, respectively, which are irrelevant to lexical processing and could potentially lead to confounds (see Rayner & Pollatsek, 1989).

To investigate this issue, Schilling et al. (1998) compared reading performance in single-word reading, using both a reading aloud and a lexical decision task, to reading performance in sentence reading, using eye movement recordings. The experimental manipulation of interest in their study was the frequency of the target word. Eye movement measures correlated with response latencies in both reading aloud and lexical decision. In a similar study, Kuperman et al. (2013) found that response latencies in lexical decision and reading aloud correlated with each other; however, eye movement measures correlated less strongly with response latencies in either lexical decision or reading aloud. In other words, there was more variance shared between reading aloud and lexical decision than between either of these tasks and eye movement measures. Critically, the assumption that a common underlying mechanism might have been responsible for the effects observed across some of the tasks in the two above-mentioned studies is not justified (see Grainger, 2003). For example, effects of orthographic neighbourhood density have often been found to be facilitatory in nature in both reading aloud and lexical decision (e.g. Andrews, 1989), yet the underlying mechanisms that induce such facilitation differ considerably in the two tasks (Grainger & Jacobs, 1996).

More specifically, in relation to reading particle and prefixed verbs, previous work in this domain focused on single (i.e. isolated) word reading. However, rarely do readers need to recognise morphologically complex verbs presented in isolation, because these verbs typically occur in a sentence or a text context (see Rayner & Liversedge, 2011, for a similar point). Also, the primary difference between particle and prefixed verbs is the separable nature of the constituent morphemes of the former, in contrast to that of the latter, which only becomes relevant in a sentence context. Accordingly, one might expect that potential differences in the processing of the two types of verbs might only arise when the verbs are presented in a natural reading environment (e.g. sentence reading). Eye movement recordings can provide additional insights into the processing of particle and prefixed verbs during sentence reading. Given that particles are free morphemes that can stand alone in a sentence, parafoveal processing of particles in particle verbs could well differ in nature from parafoveal processing of prefixes in prefixed verbs, which might then have an impact on word recognition processes. Potential differences between the two types of verbs are thus likely to manifest during the early stages of the reading process and to be reflected in word fixation durations, which highlights the importance of investigating this issue using eye-tracking.

Present study

To our knowledge, no studies have investigated how particle and prefixed verbs are processed during sentence reading using an eye-tracking paradigm. The use of eye-tracking in the current investigation is particularly relevant, because the linear left-to-right nature of processing in sentence reading (Kwantes & Mewhort, 1999) allows us to determine (via the use of certain eye movement measures) whether particles are indeed processed as separate lexical entities. To achieve this, we employed the design of an eye-tracking study that used the gaze-contingent boundary paradigm in sentence reading (Juhasz et al., 2008). In this paradigm, a preview item is presented parafoveally and is replaced by the target word when participants' eyes cross an invisible boundary preceding the target word. On the assumption that particles in particle verbs trigger the segmentation process faster than prefixes in prefixed verbs, because of their "free-standing" feature, facilitation in the processing of the former type of verbs should be reflected in several eye movement measures.

Using this paradigm, Juhasz et al. (2008) created a blank preview condition in which word length information was manipulated in the parafovea by deleting a letter in compound words (e.g. *backhand* -> *back and*). The blank preview condition is thought to disrupt the normal reading process. We considered this manipulation particularly relevant for exploring potential differences in the processing of particle and prefixed verbs. This is because by inserting a blank after the particle in particle verbs (e.g. *abbauen* -> *ab auen*), or the prefix in prefixed verbs (e.g. *bebauen* -> *be auen*), both particles and prefixes stand out, thus becoming salient to the reader. Particles are free-standing morphemes that are routinely separated from the stem, whereas prefixes are bound to the stem and cannot stand alone in a sentence. Accordingly, the blank preview condition should be far less disruptive for particle verbs than for prefixed verbs, causing less inhibition in the processing of the former compared to the latter. In other words, smaller processing differences should be observed between a blank and an identity preview condition for particle verbs (i.e. *ab auen* vs. *abbauen*) than for prefixed verbs (i.e. *be auen* vs. *bebauen*).

Furthermore, Juhasz et al. (2008) created an orthographic preview condition in which the first letter of the second constituent of a compound word was replaced with a visually similar letter (e.g. *backhand* -> *backband*). Differences between this condition and an identity preview condition (e.g. *backhand* -> *backhand*) would indicate that detailed orthographic information is encoded parafoveally. On the assumption that detailed

orthographic information is indeed obtained when an orthographic preview manipulation is used with particle and prefixed verbs (e.g. *abbauen* -> *ablauen*, *bebauen* -> *belauen*, respectively), particles should be more informative than prefixes, because they correspond to a lexical entity (i.e. *ab* in *ablauen* is a word, whereas *be* in *belauen* is not). Accordingly, the orthographic preview condition should create a processing benefit for particle verbs compared to prefixed verbs. As a result, smaller processing differences should be observed between *ablauen* and *abbauen* than between *belauen* and *bebauen*. It is also worth noting that effects observed in the blank preview condition could be also potentially due to the detection of a visual change between preview and target, and so the use of an orthographic preview condition was necessary for determining whether skilled readers encode indeed detailed orthographic information parafoveally.

Method

Participants. Thirty-five adults (25 females) from the Berlin area participated in the study for monetary compensation. Participants were native speakers of German, between 18 and 36 years old ($M = 27.2$, $SD = 4.9$), had normal or corrected-to-normal vision, and reported no hearing, reading, or language difficulties. Five female participants were excluded from the analyses, either due to a high percentage of tracking loss ($> 40\%$, $N = 3$), or due to low performance on the SLRT II (Moll & Landerl, 2010) reading test ($N = 1$), or due to a technical error ($N = 1$). Thus, 30 participants (20 females) were included in the final analysis. Participants' reading performance was assessed with SLRT II. For word reading, their performance was slightly above average ($M = 59.9$, $SD = 23.6$, $t(29) = 2.296$, $p = .029$). For nonword reading, their performance did not differ significantly from the population mean ($M = 58.3$, $SD = 26.6$, $t(29) = 1.701$, $p = .100$). Participants' vocabulary knowledge and non-verbal intelligence were assessed with the CFT-20R Vocabulary and Matrices subtests (Weiß, 2006), respectively. Their average accuracy was 95% on the Vocabulary subtest and 70% on the Matrices subtest. The study was approved by the ethics committee of the Max Planck Institute for Human Development. Participants gave written informed consent before participating in the study.

Materials. Target words consisted of 99 particle verbs (e.g. *abbauen* - "to dismount something") and 99 prefixed verbs (e.g. *bebauen* - "to construct buildings upon") extracted from the DWDS corpus (Digitales Wörterbuch Deutscher Sprache, version 0.4, January 2014;

Geyken, 2007). Particle verbs contained high-frequency verb particles (i.e. *ab-*, *an-*, *aus-*, *ein-*, *vor-*) and prefixed verbs contained high-frequency verb prefixes (i.e. *be-*, *ent-*, *er-*, *ver-*, *zer-*). Targets in each verb condition had identical letter length ($M = 8.9$, $SD = 0.9$, range = 7-10). We also sought to match particle and prefixed verbs on psycholinguistic variables that are thought to influence reading processes, such as word frequency, Orthographic Levenshtein distance (OLD20; Yarkoni et al., 2008), and bigram frequency (see Table 1). OLD20 is a lexical density index; the higher its value, the sparser its orthographic neighbourhood. Bigram frequency was calculated by log-transforming first the individual bigram frequencies for each item, and then by summing them up. Even though particle and prefixed verbs did not differ significantly in terms of whole-word frequency ($t(98) = 0.266$, $p = .791$), they did differ in terms of OLD20 ($t(98) = 3.961$, $p < .001$) and bigram frequency ($t(98) = -6.297$, $p < .001$), with prefixed verbs having slightly higher bigram frequency and more orthographic neighbours than particle verbs. We took such differences into account in our analyses by including OLD20 and bigram frequency in the statistical models. In addition, we used word-embedding vectors from the pre-trained German model provided in the *fastText* database (<https://fasttext.cc>; Bojanowski et al., 2017) to quantify the semantic transparency of each verb. Semantic transparency was defined as the cosine between the particle verbs and their embedded stem (e.g. *abbauen* vs. *bauen*), and the prefixed verbs and their embedded stem (e.g. *bebauen* vs. *bauen*). Overall, particle and prefixed verbs were equally related to their embedded stems ($t(98) = 0.148$, $p = .883$). The psycholinguistic properties of the target words are provided in Table 1.

Target verbs were embedded in sentences in the future tense or in combination with a modal verb, both of which require the target verb in the infinitive form (see Supplementary Material). Target verbs occupied primarily the 5th ($N = 95$) or 6th ($N = 83$) position in the sentence, or in a few cases the 7th ($N = 14$), 8th ($N = 5$), or 9th ($N = 1$) position. Importantly, targets were always followed by one or more words, and were preceded by content words. The preceding content words were matched across the two verb type conditions on lemma frequency (particle: $M_{(\log_{10})} = 1.8$, $SD = 0.9$, prefixed: $M_{(\log_{10})} = 1.8$, $SD = 1.0$, $t(196) = -1.241$, $p = .216$), and length in characters (particle: $M = 6.4$, $SD = 2.0$, prefixed: $M = 6.7$, $SD = 2.3$, $t(196) = -0.898$, $p = .371$). Words following the target verbs were also matched across the two conditions on lemma frequency (particle: $M_{(\log_{10})} = 3.9$, $SD = 0.6$, prefixed: $M_{(\log_{10})} = 3.9$, $SD = 0.6$, $t(196) = 0.147$, $p = .884$), and length in characters (particle: $M = 4.2$, $SD = 1.5$, prefixed: $M = 4.1$, $SD = 1.4$, $t(196) = 0.642$, $p = .521$).

Sentence length ranged between 6 and 14 words (34–79 characters). Mean sentence length in characters was similar across the two conditions (particle: $M = 60.3$, $SD = 9.0$, prefixed: $M = 61.8$, $SD = 8.7$, $t(196) = -1.158$, $p = .248$). Each sentence was displayed on a single line of text.

For each target word, three different parafoveal preview conditions were created. In the *identity preview* condition, the preview word was identical to the target word. In the *orthographic preview* condition, the first letter of the base verb was replaced by another visually similar letter, creating a nonword (e.g. *abbauen* → *ablauen*, *bebauen* → *belauen*). Care was taken to form phonotactically legal bigram and trigram letter combinations. In the *blank preview* condition, the first letter of the base verb (i.e. the letter following the particle or prefix, respectively) was replaced by a blank space (e.g. *abbauen* → *ab auen*, *bebauen* → *be auen*).

Norms for target word predictability for each sentence were collected in an independent study that involved 14 participants who did not participate in the eye-tracking study (11 females, $M = 28.9$, $SD = 4.3$, range: 21–34 years). Word predictability refers to how predictable a certain word is when the preceding part of the sentence is known. Participants performed a cloze task on the experimental sentences, which consisted of trying to anticipate the following word based on the preceding part of the sentence. Results showed that in three out of 198 sentences, the target word reached a predictability rate of more than 25%. These sentences were replaced by new ones. The mean predictability of the remaining target words was very low for both verb types (particle verbs: $M = .02$, $SD = .04$; prefixed verbs: $M = .01$, $SD = .03$). Hence, the target words in our sentences were rarely predictable from the preceding context. This was very important, because words that are predictable from prior text are more likely to be skipped than unpredictable words (Balota et al., 1985; Drieghe et al., 2005; Rayner & Well, 1996).

Apparatus. An EyeLink 1000 eye tracker (SR Research Ltd) was used to record eye movements during reading at a rate of 1000 Hz. Sentences were presented on a 21" ASUS LCD monitor, with a refresh rate of 120 Hz and a resolution of 1024 × 768 pixels. Participants sat at a viewing distance of 60 cm with an assisting head and chin rest to reduce head movements. The words comprising the sentences were presented in black 14-point Courier New font (corresponding to 0.35° degrees of visual angle per letter) on a white background. The task was programmed in SR Research Experiment Builder (2011) using the gaze-contingent boundary paradigm (Rayner, 1975). In particular, target words were presented in the three preview conditions with an invisible boundary set up at the blank space

Table 1. Psycholinguistic properties of target words.

	Lemma frequency (log10)		Bigram frequency		OLD20		Semantic transparency	
	<i>M</i> (<i>SD</i>)	Range	<i>M</i> (<i>SD</i>)	Range	<i>M</i> (<i>SD</i>)	Range	<i>M</i> (<i>SD</i>)	Range
Particle	0.15 (0.7)	−1.4–1.8	50.5 (5.2)	38.5–59.9	1.74 (0.2)	1.3–2.5	0.55 (0.1)	0.2–0.8
Prefixed	0.10 (0.7)	−2.1–1.6	50.95 (5.1)	39.6–59.7	1.67 (0.2)	1–2.5	0.55 (0.1)	0.3–0.8

preceding the target word. When participants' eyes crossed the boundary, a display change was triggered and the preview item was replaced by the target word, which remained on the screen until the participants finished reading the sentence.

Procedure. Three lists were created using a Latin square design, so that each target word appeared only once within a list, and once in each of the three preview conditions across the three lists. As such, in each list, 33 out of 99 targets for each verb type (particle and prefixed) were preceded by an identity preview, 33 were preceded by an orthographic preview, and 33 were preceded by a blank preview. Within each list, the two verb types with the same verb stem (e.g. *abbauen* and *bebauen*) were presented in the same preview condition. Ten participants were assigned to each list. The order of sentence presentation within each list was randomised across participants. Each participant read a total of 198 experimental sentences (99 sentences per verb type) and 54 filler sentences, which were presented intermixed with the experimental sentences. In total, each participant read 252 sentences. All of the sentences used in the study, as well as the items in the different preview conditions in the experimental sentences, are provided in the Supplementary Material.

Testing took place at the eye-tracking lab of the Max Planck Institute for Human Development in Berlin. A five-dot calibration of the eye tracker was conducted and validated with each participant until calibration accuracy below 0.4° was achieved. The eye tracker was recalibrated after four practice trials and after each block, which comprised 18 sentences, or when *x*- or *y*-axis drift was detected. Participants were instructed to read each sentence silently and press a button on a gamepad with their right thumb, once they had read the sentence. One-third of the sentences were followed by a forced-choice comprehension question with the answers displayed at the bottom right and left corners of the screen. Participants were instructed to select the correct answer by clicking the right or left buttons on the gamepad using their right and left index fingers, respectively. Every four blocks a short break was administered. The experiment began with a practice session, which consisted of four sentences followed by comprehension questions. The experimental session lasted between 1 and 1.5 hours.

Eye movement measures. Skilled readers tend to skip words during reading. Function words, for example, are

fixated only about 35% of the time, while content words are fixated about 85% of the time (Rayner, 2009). Typically, as word length increases, the probability of fixating the word increases too (Rayner & McConkie, 1976; Rayner et al., 1996). In addition, longer words are often fixated more than once (i.e. refixated) prior to moving to another word (see McConkie et al., 1989; McDonald & Shillcock, 2004; Vergilino & Beauvillain, 2000). To account for both skipping and refixations in eye movement data a number of eye movement measures have been developed. Some of these measures are skipping rate, which corresponds to the percentage of cases in which the target word is not fixated on the first pass; first fixation duration, which represents the duration of the very first fixation on the target word during the first pass, irrespective of number of fixations; single fixation duration, which represents the duration of the first fixation on the target word if it only received one fixation during the first pass; and gaze duration, which corresponds to the sum of all first pass fixations on the target word (Juhász & Pollatsek, 2011). In those cases where the reader fixates the target word only once, first fixation duration, single fixation duration, and gaze duration for that word are identical. Therefore, these three measures only differ if refixations are taken into account.

More specifically, first fixation duration, which is typically sensitive to initial processing difficulty associated with the target word, is considered as an early index of lexical access. For example, a few studies have found longer first fixation durations for low-frequent than for high-frequent words (e.g. Inhoff & Rayner, 1986; Raney & Rayner, 1995; Rayner & Duffy, 1986), and for words in syntactically-ambiguous sentences compared to the same words in non-ambiguous versions of these sentences (e.g. Murray & Liversedge, 1994; Rayner et al., 1983). However, first fixations can sometimes be short due to landing errors. In these cases, a quick saccade is usually made towards the intended landing position and the word is refixated. Single fixation duration is not subject to cases in which words are refixated as a result of faulty landing, and so it is sometimes considered as a better alternative to first fixation duration (Kuperman et al., 2013). Moreover, first fixation duration is not always susceptible to initial processing difficulty. Long words, for example, are often refixated; in that case, gaze duration is more likely to reflect initial processing

difficulty. Therefore, reporting a combination of measures minimises the possibility of failing to detect an experimental effect. For this reason, when the unit of analysis is a single word, all related measures are typically reported (Liversedge et al., 1998). Of course, this does not mean that there are no occasions where a certain measure might be preferred to another. For example, for short words (e.g. 2–3 letters long), which are more often skipped than fixated, skipping rate is usually the preferred measure (Brysbaert et al., 2005). For words of medium length (e.g. 4–8 letters long), single fixation duration is thought to be the most appropriate measure, as these words are shorter than the average saccade length, which is about 8 letters, and are therefore likely to be processed in a single fixation (Kuperman et al., 2013). For long words (e.g. with more than 8 letters), gaze duration is considered as the most sensitive measure of word recognition time, because refixations occur then frequently (see Rayner et al., 1996).

Considering all of the above, and given that our target items ranged in length between 7 and 10 letters, we analysed our data in terms of first fixation duration (FFD), single fixation duration (SFD), and gaze duration (GD). We hypothesised that any potential differences in the processing of particle and prefixed verbs in the three preview conditions would be reflected in some or all of these measures. Furthermore, we took into account an additional measure, that is, initial landing position (ILP), which is commonly known as landing site (McConkie et al., 1988) and corresponds to the initial fixation location on the target word. This measure is particularly relevant for the present study, as morphological influences on ILP have been recently observed in two morphologically rich languages, namely, Uighur (Yan et al., 2014) and Finnish (Hyönä et al., 2018). The idea entertained by Hyönä and colleagues is that readers might perceive parafoveally morphological units (e.g. particles and prefixes), as these units correspond to highly frequent letter clusters. As a result, readers might then launch a saccade away from the particle or the prefix, with initial fixation landing closer to the middle of the stem, thus facilitating the recognition process. We reasoned that thanks to their “free-standing” nature, particles might be more salient than prefixes parafoveally. If that were the case, ILP would differ as a function of verb type, with ILP further into the word in the particle verb condition than in the prefixed verb condition, indicating faster recognition of particle verbs than of prefixed verbs. Furthermore, we hypothesised that potential processing differences between particle and prefixed verbs would be reflected in the blank preview condition compared to the identity preview condition, and in the orthographic preview condition compared to the identity preview condition.

Analysis

Analyses were performed using (generalised) linear mixed-effects models (Baayen et al., 2008) as implemented in the *lme4* package (Version 1.1-21; Bates et al., 2015) in the statistical software R (Version 3.6.1, 2019-07-05, “Action of the Toes”, R Core Team, 2018). The significance of the fixed effects was determined with type III model comparisons using the *Anova* function in the *car* package (Version 3.0-4; Fox & Weisberg, 2019). When necessary, post hoc comparisons were carried out using cell means coding and single *df* contrasts with the *glht* function of the *multcomp* package (Version 1.4-10; Hothorn et al., 2008) using the normal distribution to evaluate significance.

FFD, SFD, and GD were log-transformed to normalise residuals. Models included the effect-coded fixed effects of Preview Type (Identity vs. Orthographic vs. Blank), Verb Type (Particle vs. Prefixed), and Trial Order, as well as their interaction. Trial Order did not interact with the other factors in a critical way; hence, it was subsequently modelled as a main effect. OLD20 and bigram frequency were also included in the model to account for the significant differences that were observed between particle and prefixed verbs on these variables. Random intercepts and random slopes for the effect of Preview Type were used for both participants and items. The model means for all eye movement measures are shown in Table 2 and the results from the mixed-effects analyses are provided in Table 3.

A post-hoc power analysis was conducted in R using the *simr* package (Version 1.0.5; Green & MacLeod, 2016). We carried out simulations by steadily increasing the differences between particle and prefixed verbs on our four dependent variables, while observing the power for each difference. We did this separately for the orthographic and the blank preview condition. The simulation results were quite similar for the two preview conditions, so we only report them for the former. With regard to the particle versus prefixed verb difference, our results showed that we had a power of .80 to detect an effect of 0.15 letters in ILP, 7 ms in FFD and SFD, and 10 ms in GD. These effects are very small as far as eye movement measures are concerned, which indicates that our study is not underpowered.

Trials in which participants blinked while reading the target word, trials in which the pre-target word was skipped, and trials in which the display change occurred too early or later than 10 ms after the post-boundary word was fixated (see Slattery et al., 2011) were excluded from the analyses. These exclusions accounted for 21% of the data. In addition, sentences in which five or more regressions occurred and sentences which

Table 2. Mean model initial landing position (letters), first fixation duration (milliseconds), single fixation duration (milliseconds), and gaze duration (milliseconds) to targets by verb type and preview type (SEs in parentheses).

Variables	Particle verbs				Prefixed verbs			
	ILP	FFD	SFD	GD	ILP	FFD	SFD	GD
Preview Type								
Identity	4.1 (0.1)	233 (8)	237 (9)	262 (11)	4.1 (0.1)	230 (8)	237 (9)	260 (11)
Orthographic	4.0 (0.1)	236 (8)	245 (9)	268 (11)	4.1 (0.1)	233 (8)	242 (9)	269 (11)
Blank	3.8 (0.2)	234 (8)	252 (9)	288 (11)	3.9 (0.2)	234 (8)	253 (9)	290 (11)

Note: ILP: Initial Landing Position; FFD: First Fixation Duration; SFD: Single Fixation Duration; GD: Gaze Duration.

received more than 20 fixations were excluded (0.6% of the data). Also, target words that were skipped during first-pass reading, reread more than three times, or fixated more than five times, were excluded from any further analyses (0.9% of the data). During first-pass reading, 75% of the target words were fixated once, 23% were fixated twice, and 2% were fixated three or more times. Average comprehension accuracy was 98% ($SD = 1\%$, range: 95-100%).

All data and the R code corresponding to the present analyses are available via the Open Science Framework (OSF; <https://osf.io/feqn5/>).

Results

Initial landing position. Results from the analysis of ILP showed a significant main effect of Preview Type. Initial landing position in the blank preview condition ($M = 3.9$, $SE = 0.2$) was significantly closer to the beginning of the target word ($\Delta = 0.3$, $z = -2.548$, $p = .011$) than in the identity preview condition ($M = 4.1$, $SE = 0.1$). Also, initial landing position in the orthographic preview condition ($M = 4.0$, $SE = 0.1$) was significantly closer to the beginning of the target word ($\Delta = 0.1$, $z = -2.080$, $p = .038$) than in the identity preview condition. The main effect of Verb Type and its interaction with Preview Type were not significant.

We further evaluated the non-significant Verb Type by Preview Type interaction by comparing initial landing position for particle and prefixed verbs in each preview type. These were far from being significant: blank ($z = -1.357$, $p = .175$), orthographic ($z = -0.667$, $p = .505$), identity ($z = 0.198$, $p = .843$). To quantify evidence for the null interaction (see Rouder et al., 2009), we also calculated the Bayes factor to compare the model we report against the model that did not include the Verb Type by Preview Type interaction. The model without the interaction term was preferred by a factor of about 62 ($\pm 5.5\%$), which according to Jeffreys (1961) provides “very strong evidence” for the hypothesis that the effect of Verb Type is not modulated by Preview Type.

First fixation duration. Any first fixation durations below 50 or above 1000 ms (0.02% of the data) were considered as extreme values and were removed. Outliers

were subsequently removed following the procedure outlined by Baayen and Milin (2010). In particular, a base model, which included only participants and items as random intercepts, was fitted to the data and data points with residuals exceeding 2.5 SDs were removed (2.5% of the data). Results showed no significant main effects or interactions.

The non-significant Verb Type by Preview Type interaction was further evaluated by comparing first fixation duration for particle and prefixed verbs in each preview type. These were far from being significant: blank ($z = 0.07$, $p = .944$), orthographic ($z = 0.944$, $p = .345$), identity ($z = 1.003$, $p = .316$). The Bayes factor analysis revealed that the model without the interaction term was preferred by a factor of about 137 ($\pm 2.8\%$), which provides “extreme evidence” for the hypothesis that the effect of Verb Type is not modulated by Preview Type.

Single fixation duration. Any single fixation durations below 50 or above 1000 ms (0.03% of the data) were considered as extreme values and were removed. Outliers were then removed in the same way as for the FFD analysis (2.4% of the data). Results showed a significant main effect of Preview Type. Targets in the blank preview condition ($M = 253$ ms, $SE = 9$) yielded significantly longer single fixation durations ($\Delta = 16$ ms, $z = 4.174$, $p < .001$) than targets in the identity preview condition ($M = 237$ ms, $SE = 9$). Also, targets in the orthographic preview condition ($M = 244$ ms, $SE = 9$) yielded significantly longer single fixation durations than targets in the identity preview condition ($\Delta = 6$ ms, $z = 2.553$, $p = .011$). Importantly, the main effect of Verb Type and its interaction with Preview Type were not significant, indicating similar effects of preview type for particle and prefixed verbs.

The non-significant Verb Type by Preview Type interaction was further evaluated by comparing single fixation duration for particle and prefixed verbs in each preview type. These were far from being significant: blank ($z = -0.363$, $p = .717$), orthographic ($z = 0.889$, $p = .374$), identity ($z = -0.049$, $p = .961$). The Bayes factor analysis showed that the model without the interaction term was preferred by a factor of about 89 ($\pm 2.6\%$), which provides “very strong evidence” for the hypothesis that the effect of Verb Type is not modulated by Preview Type.

Table 3. Analysis of variance for initial landing position, first fixation duration, single fixation duration, and gaze duration.

Variables	ILP		FFD		SFD		GD	
	χ^2	<i>p</i>	χ^2	<i>p</i>	χ^2	<i>p</i>	χ^2	<i>p</i>
Fixed effects (<i>df</i>)								
Intercept (1)	1409.859	<.001	30,223.917	<.001	24,771.324	<.001	20,957.617	<.001
Verb Type (1)	0.880	=.348	0.825	=.364	0.047	=.828	0.006	=.940
Preview Type (2)	8.411	=.015	2.948	=.229	17.425	<.001	56.833	<.001
Verb Type*Preview Type (2)	1.783	=.410	0.773	=.679	1.187	=.552	0.442	=.802
Trial Order	19.924	<.001	1.820	=.177	4.406	=.036	18.370	<.001
OLD20	1.162	=.281	0	=.997	1.072	=.300	7.015	=.008
Bigram frequency	40.343	<.001	0.152	=.697	0.528	=.467	9.975	=.002

Gaze duration. Any gaze durations below 50 or above 1000 ms (0.2% of the data) were considered as extreme values and were removed. Outliers were removed in the same way as for the other measures (2.0% of the data). Results showed a significant main effect of Preview Type. Targets in the blank preview condition ($M = 289$ ms, $SE = 11$) yielded significantly longer gaze durations ($\Delta = 28$ ms, $z = 7.432$, $p < .001$) than targets in the identity preview condition ($M = 261$ ms, $SE = 11$). Also, targets in the orthographic preview condition ($M = 269$ ms, $SE = 11$) yielded significantly longer gaze durations than targets in the identity preview condition ($\Delta = 8$ ms, $z = 2.766$, $p = .006$). Critically, the main effect of Verb Type and its interaction with Preview Type were not significant, indicating similar effects of preview type for particle and prefixed verbs.

We further evaluated the non-significant Verb Type by Preview Type interaction by comparing gaze duration for particle and prefixed verbs in each preview type. These were far from being significant: blank ($z = -0.379$, $p = .705$), orthographic ($z = -0.165$, $p = .869$), identity ($z = 0.363$, $p = .717$). The Bayes factor analysis showed that the model without the interaction term was preferred by a factor of about 143 ($\pm 3.9\%$), which provides “extreme evidence” for the hypothesis that the effect of Verb Type is not modulated by Preview Type.

General discussion

Particle verbs form a unique feature of Germanic languages. Just like prefixed verbs, they are morphologically complex; yet in contrast to prefixed verbs, their constituent morphemes are routinely separated from each other, and can thus stand alone in a sentence. This characteristic of particle verbs is particularly relevant for research on morphological processing in reading. More specifically, morphologically-structured printed words are thought to be segmented into their constituent morphemes during reading. On the assumption that the “free-standing” feature of particles enables their mapping onto pre-existing whole-word representations, which trigger the segmentation process (as per the embedded-stem activation account of Grainger &

Beyersmann, 2017), we would expect processing differences between particle verbs and prefixed verbs. In particular, particle verbs should be segmented faster into their constituent morphemes than prefixed verbs. Faster segmentation of particle verbs should in turn facilitate the identification of the corresponding morphemes, thus speeding up the recognition of particle verbs compared to prefixed verbs during reading. We tested this idea in the present study using an eye-tracking paradigm in a sentence-reading task. We hypothesised that potential processing differences between the two types of verbs might indeed arise when the verbs are presented in a natural reading context.

The sentence-reading task employed the gaze-continuent boundary paradigm in eye-tracking. Target words corresponded to particle (e.g. *abbauen*) and prefixed (e.g. *bebauen*) verbs. Three parafoveal preview conditions were created: identity (e.g. *abbauen*, *bebauen*), blank (e.g. *ab auen*, *be auen*), and orthographic (e.g. *ablauen*, *belauen*). Initial landing position, first fixation duration, single fixation duration, and gaze duration, were analysed. No significant differences in the processing of particle and prefixed verbs were observed in any of these measures. With regard to the preview conditions, the blank and orthographic conditions yielded longer single fixation durations and gaze durations compared to the identity condition. Furthermore, participants’ eyes landed significantly closer to the word beginning in the blank and orthographic preview conditions, but further into the word in the identity preview condition, which suggests that German readers were able to extract orthographic information from the parafovea during sentence reading. However, critically for the present study, the observed preview effects were not modulated by verb type, indicating no processing differences between particle and prefixed verbs during reading.

The disruptive nature of the blank preview condition has been demonstrated in a few studies that manipulated word length information in the parafovea by either deleting a letter in compound words (e.g. *backhand* -> *back and*; Juhasz et al., 2008), or deleting the fourth letter of target words (e.g. *subject* -> *sub ect*;

Inhoff et al., 2003), or inserting an “s” between two words (e.g. *bomb under* -> *bombsunder*; White et al., 2005). In all of these studies, results showed that fixation durations on the target word were longer when the preview contained incorrect word length information. Our results agree with those obtained in these studies. We observed that single fixation duration and gaze duration were significantly longer in the blank preview condition compared to the identity preview condition. Also, we found that initial landing position was significantly closer to word beginning in the blank preview condition compared to the identity preview condition. This is because the presence of a blank in the preview item prevents readers’ eyes from landing at the optimal viewing position, which is thought to be slightly to the left of the centre of a word (McConkie et al., 1988). It is worth noting that no significant differences between the blank and identity preview conditions were observed for first fixation duration. This measure is taken to be the earliest point at which an effect might be observed due to the experimental manipulation, as this is the first time the reader has directly fixated the region that induces processing difficulty (see Liversedge et al., 1998). The lack of such an early effect could be due to the use of relatively long target words (7-10 letters long), which typically need to be refixated before lexical access can be achieved.

Furthermore, the orthographic preview condition yielded longer single fixation durations and gaze durations compared to the identity preview condition. However, this was not the case in the Juhasz et al. (2008) study. We believe that the discrepancy of the findings between the two studies may be due to the fact that the substituted letter in the preview item was closer to the beginning of the word in our study (third or fourth letter) than in the Juhasz et al. (2008) study, where any letter between the third and seventh position was substituted. As such, the letter change in the orthographic preview condition was more salient in our study due to higher visual acuity. In addition, the finding that initial landing position was closer to word beginning in the orthographic preview than in the identity preview condition indicates that detailed orthographic information must have been encoded parafoveally, and that the observed effects are not just due to the detection of a visual change between preview and target. Moreover, we ensured that all nonwords in the orthographic preview condition were phonotactically legal, because irregular letter combinations tend to attract readers’ attention (see e.g. Hyönä, 1995). On the basis of the present findings we can thus be confident that orthographic representations of particle and prefixed verbs were activated parafoveally during sentence reading.

The absence of a difference in the processing of particle and prefixed verbs during sentence reading is consistent with another finding reported by Juhasz et al. (2008). In particular, in their Experiment 4, a morphological preview condition was created, in which either the first or the second letter of the second constituent of a compound word was deleted (e.g. *sawdust* -> *saw ust* and *sawdust* -> *sawd st*, respectively). Varying the location of the “blank” in the preview item led to the creation of two sub-conditions: one in which the first constituent of the preview corresponded to a lexical entity (i.e. *saw* in *saw ust*) and another in which the first constituent of the preview corresponded to a nonword (e.g. *sawd* in *sawd st*). Results showed no significant differences between the two types of preview in terms of the examined eye movement measures. In our blank preview condition, the first constituent of our morphologically complex verbs either corresponded to a lexical entity (e.g. the particle *ab* in *ab auen*) or a nonword (e.g. the prefix *be* in *be auen*). Similarly to Juhasz et al. (2008), we observed no significant differences between the two, independently of the lexical status of the first constituent.

Our results are also consistent with those obtained by Smolka et al. (2019) who investigated semantic transparency effects on the processing of particle and prefixed verbs and found a similar pattern of results for both types of verbs. In the present study, we focused on earlier processing stages. Taken together, the effects observed by Smolka et al. (2019) and those obtained in the present study provide evidence in favour of the idea that particle and prefixed verbs are processed similarly both at the early and later stages of word recognition. How can we explain the absence of a difference in the processing of particle and prefixed verbs? Particle verbs are thought to be acquired earlier during language development than prefixed verbs (Behrens, 1998). This could well be because the separable nature of the constituent morphemes of particle verbs facilitates their acquisition early in development. However, as we mentioned in the Introduction, both particle and prefixed verbs are highly productive in the German language, while some of them are homographic (see endnote 2). In other words, despite their differences, particle and prefixed verbs have many characteristics in common (see also Smolka et al., 2019, for a similar argument). Therefore, it is likely that increased exposure to both types of verbs through language use enables the reading system to pick up their similarities and productivity in the language, thus resulting in the development of similar morphologically-structured mental representations for both (at least as far as the skilled reading system is concerned).

Last, on the basis of the idea that free-standing morphemes might be mapped onto pre-existing whole-word representations, which could then trigger the segmentation process, as per the embedded stem activation account (Grainger & Beyersmann, 2017), we hypothesised processing differences between particle and prefixed verbs, because particles occur as free-standing morphemes, whereas prefixes do not. However, we did not observe such differences. Our results suggest, thus, that the “free-standing” feature of morphemes might not be the sole factor modulating morphological segmentation processes during reading. More generally, our findings suggest that the segmentation of morphologically complex words is independent of the idiosyncratic characteristics of a language (see Ciaccio et al., 2020, for a similar conclusion), thus providing support for a theory of reading that adopts universal principles with regard to this specific morphological process.

Notes

1. Note that particle verbs, which are orthographically written as one word but separated in certain syntactic constructions, are only found in German, Dutch, and Frisian (Blom, 2005).
2. Another main difference between particle and prefixed verbs is their stress pattern. Particles are prosodically strong; hence, the primary stress falls on the particle (*'aussehen*). In prefixed verbs, it is the stem that receives the stress (*be'sehen*). It is also worth noting that *durch-*, *hinter-*, *über-*, *um-*, and *unter-* can be both particles and prefixes. When combined with a stem, the resulting homographic verbs have different meanings and a different stress pattern (e.g., particle verb: *'umfahren*, “to knock down something”; prefixed verb: *um'fahren*, “to drive around something”).

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