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EMPIRICAL STUDY

Variability and Consistency in First and Second Language Processing: A Masked Morphological Priming Study on Prefixation and Suffixation

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Word forms such as *walked* or *walker* are decomposed into their morphological constituents (walk + –ed/–er) during language comprehension. Yet, the efficiency of morphological decomposition seems to vary for different languages and morphological types, as well as for first and second language speakers. The current study reports results from a visual masked priming experiment focusing on different types of derived word forms (specifically prefixed vs. suffixed) in first and second language speakers of German. We compared the present findings with results from previous studies on inflection and compounding and proposed an account of morphological decomposition that captures both the variability and the consistency of morphological decomposition for different morphological types and for first and second language speakers.

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Introduction

Much research in linguistics has focused on what is common (perhaps even universal) across different languages and among different speakers of a language. At the same time, variability due to geographical or social factors, for example, is also a hallmark of language and language use. Variability may even occur within a single speaker depending on the context in which language is used. Yet, variability in language and language performance is limited by such factors as linguistic and cognitive constraints.

Psycholinguistic research faces the same challenge of disentangling variability in language production and comprehension from more general (perhaps universal) mechanisms of language processing. Consider a well-known finding from experimental research on morphologically complex words: A range of studies examining both derived (*player*) and inflected (*played*) word forms have provided support for an automatic decomposition mechanism that segments these word forms into their morphological constituents (for a review, see Marslen-Wilson, 2007). This mechanism is supposed to be ubiquitous, operating across different languages and types of morphologically complex words (Rastle, Davis, Marslen-Wilson, & Tyler, 2000; Rastle, Davis, & New, 2004). Yet, the efficiency with which morphological decomposition operates may vary depending on both linguistic properties of the complex forms involved and for different groups of speakers. To take an example, Jacob, Heyer, and Verı́ssimo (2018) found priming effects indicative of morphological decomposition to be reduced in second language (L2) speakers (despite advanced levels of L2 proficiency), but only for inflected words, not derived, whereas native (L1) speakers showed parallel decomposition effects for both morphological processes. Here we distinguish between morphological processes (such as derivation, inflection, and compounding) and morphological types (such as prefixed vs. suffixed word forms).

One approach of dealing with this kind of variability is through specialization, that is, by developing models of language processing—in the present case, accounts of morphological decomposition—that hold for L1 speakers only. Such models may be detailed and precise, and they have a clearly defined scope. Indeed, current psycholinguistic models in this domain are essentially accounts of L1 morphological processing based on experimental studies with adult L1 speakers (for a review, see Amenta & Crepaldi, 2012). The present study pursues a different approach by developing an account of morphological decomposition that includes evidence from both L1 and L2 speakers aimed at capturing both linguistic and group-level sources of variability of morphological decomposition. To this end, we employed the visual masked priming technique to investigate derived words of German representing different morphological types (namely, prefixed and suffixed forms) with different degrees of productivity and in groups of L1 and L2 speakers.

Background Literature

The idea of an early, obligatory decomposition mechanism operating on morphologically complex words originated from Taft and Forster (1975). The experimental technique that has mostly been used in recent years to investigate this mechanism is masked priming, which is believed to tap into early, prelexical stages of visual word recognition. In a masked priming experiment, participants typically perform a word/nonword (lexical) decision task on a visually presented target word that is preceded by a visual mask and a prime word, the latter of which is presented only briefly (between 30 and 70 milliseconds) to ensure that it is not consciously visible. When primes and targets are morphologically related to each other (e.g., *player–play*), target lexical decision times are normally faster, indicating facilitated recognition (priming) compared to an unrelated control condition (e.g., *lower–play*). Facilitation in such cases is attributed to morphological decomposition of the prime word ([play] –er), thereby isolating its morphological constituents, which then directly facilitates recognition of the target word *play*.

For derived word forms, a considerable number of masked priming studies have reported significant morphological priming effects in visual masked priming experiments for different languages. The vast majority of these studies have investigated English, for which morphological decomposition of derived words has been shown to work efficiently not only in adult L1 speakers (e.g., Rastle et al., 2004), but also in L2 speakers (e.g., Silva & Clahsen, 2008) and in children (e.g., Beyersmann, Castles, & Coltheart, 2012). Similarly, German derived words were shown to yield robust morphological priming effects in both L1 and L2 adults (Jacob et al., 2018) and in German children (Hasenäcker, Beyersmann, & Schroeder, 2016). In French, Quémart, Casalis, and Colé (2011) reported significant masked priming effects with derived words in adults and children. Similar findings have also been reported for adult L1 speakers of Russian (Kazanina, Dukova-Zheleva, Geber, Kharlamov, & Tonciulescu, 2008), Japanese (Clahsen & Ikemoto, 2012), and Korean (Kim, Wang, & Taft, 2015). Together, the evidence from these studies suggests that early, prelexical morphological decomposition represents a widespread (perhaps universal) mechanism of processing derived words.

The efficacy with which morphological decomposition of derived words operates may, however, be affected by the specific linguistic properties of complex words, for example, by whether a complex word is prefixed or suffixed. While many studies have found morphological decomposition effects for suffixed words, it is less clear whether this holds for prefixed words. A number of studies employing unprimed lexical decision tasks found differences between how prefixed and suffixed words are processed. Hasenäcker, Schröter, and Schroeder (2017) found that children show effects of morphological decomposition for prefixed words later than for suffixed words. For L1 adults, Ferrari Bridgers and Kacinik (2017) reported that prefixed words take longer to process than suffixed words. Likewise, Bergman, Hudson, and Eling (1988) showed that lexical decision times in response to suffixed and pseudosuffixed words are similar, but pseudoprefixed words take longer to recognize than prefixed words, which suggests that stem access is automatic only in suffixed words. Colé, Beauvillain, and Segui (1989) found that suffixed words with high cumulative root frequency were recognized faster than those with low cumulative root frequency, whereas there was no such effect for prefixed words. Similar results were also found in eye movement monitoring. Beauvillain (1996) reported root frequency to affect fixation durations in suffixed but not in prefixed words, indicating that prefixed words are less efficiently decomposed down to the root than suffixed words.

On the other hand, studies that have employed masked priming have consistently found priming effects for derived words with prefixes, suggestive of prelexical decomposition for these word forms (Diependaele, Sandra, & Grainger, 2009; Forster & Azuma, 2000; Grainger, Colé, & Segui, 1991; Heide, Lorenz, Meinunger, & Burchert, 2010; Kazanina, 2011; Kim et al., 2015). Masked priming effects have also been reported for prefixed and suffixed pseudowords, that is, combinations of existing affixes and stems that result in (nonexisting) pseudowords, for example, *love* + *dom*. The results were mixed, however. Some researchers reported parallel priming effects for prefixed and suffixed pseudowords (Beyersmann, Cavalli, Casalis, & Colé, 2016; Heathcote, Nation, Castles, & Beyersmann, 2018; Mousikou & Schroeder, 2019), others showed priming for suffixed but not for prefixed pseudowords (Kim et al., 2015). Except for Beyersmann et al.'s (2016) study of pseudowords, there are (to our knowledge) no masked priming studies that directly compared prefixed and suffixed prime words on the same targets and in the same participants. Hence, the question of whether prefixed words can be decomposed prelexically as efficiently as suffixed words is still open.

Another linguistic source of variability for morphological decomposition is lexical restrictedness, that is, whether or not a morphological process applies to a limited set of lexical items. For irregular inflection, for example, reduced masked priming effects have been reported, relative to lexically unrestricted, regularly inflected words (Neubauer & Clahsen, 2009). For derivation, on the other hand, masked priming experiments (Silva & Clahsen, 2008) revealed parallel masked priming effects for both lexically restricted and unrestricted forms (*–ness* vs. *–ity*).

Language processing has also been shown to exhibit variability depending on an individual's working memory, vocabulary size, reading speed, and other factors (e.g., Borovsky, Elman, & Fernald, 2012; Hopp, 2014, 2015). Morphological decomposition in particular has been found to be influenced by an individual's spelling and vocabulary abilities (Andrews & Lo, 2013). Furthermore, whether a particular language represents an individual's L1 or a L2 has also been reported to influence morphological decomposition. A number of previous studies found that despite having reached a high level of proficiency in a given language, L2 speakers may show reduced masked priming effects relative to L1 speakers, particularly for regularly inflected word forms (Jacob et al., 2018; Kirkici & Clahsen, 2013; Silva & Clahsen, 2008). Furthermore, L2 processing of morphologically complex words has been found to be more susceptible to surface form prime–target overlap than L1 processing. Unlike L1 control groups, advanced bilinguals showed significant priming effects for orthographically related items in a number of masked priming experiments (Diependaele, Duñabeitia, Morris, & Keuleers, 2011; Feldman, Kostić, Basnight-Brown, Đurđević, & Pastizzo, 2010; Heyer & Clahsen, 2015; J. Li, Taft, & Xu, 2017; M. Li, Jiang, & Gor, 2017).

Taken together, while previous research has shown pervasive effects of morphological decomposition during word recognition, there are also indications that the efficiency with which this mechanism functions varies across different languages, different morphological types, and among L1 and L2 speakers. However, the details and limits of this variability are still largely unknown. Against this background, the current study aims to account for both the variability and consistency of morphological decomposition for different morphological types and for L1 and L2 speakers. To this end, we report results from a masked priming experiment with derived words and, in the discussion section, compare the present findings to previous studies of morphological decomposition in inflected words and compounds.

The Present Study

The experiment reported below investigated the processing of derived word forms in highly proficient late bilingual speakers of German with Russian as their L1, as well as a control group of L1 German speakers. The linguistic phenomena under study are prefixed negated adjectives and deadjectival nominalizations with suffixes, which included forms such as *unsauber* "not clean" and *Sauberkeit* "cleanness." German derivation has a large inventory of prefixes and suffixes to form derived adjectives, nouns, and adverbs. For some derivational processes, German offers lexically restricted (+R) affixes that apply to non-Germanic words of, for example, Latinate or Greek origin, and lexically unrestricted (–R) affixes which may appear on both Germanic and non-Germanic stems (for the same phenomenon in English, see Aronoff, 1976). The two derivational processes we selected for this study included both (+R) and (–R) affixes, namely, the prefixes *un–* and *in–* (e.g., *unsauber* "not clean," *inaktiv* "inactive") and the suffixes *–keit* and *–ität* (e.g., *Sauberkeit* "cleanness," *Aktivität* "activity").

With regard to negated adjectives, while both prefixes have the same function (in that they form the antonym of the stem to which they are attached), the (–R) affix *un–* can be used in combination with any stem, including non-Germanic stems (e.g., *untypisch* "atypical," *unproduktiv* "unproductive"), whereas the (+R) affix *in–* only occurs on non-Germanic stems. Deadjectival nominalizations offer the same (±R) contrast for suffixed forms. Both *–keit* and *–ität* derive a noun from an adjective that denotes the property expressed by the adjective. However, the suffix *–keit* (at least in its variant *–heit*) is (–R) in that it occurs on both Germanic and non-Germanic stems (cf. *Gesundheit* "health" and *Diszipliniertheit* "disciplinedness"). By contrast, the suffix *–ität* (+R) is restricted to non-Germanic stems (for further details, see Fleischer & Barz, 2007, pp. 65–66 and 269–274).

With materials constructed from these two phenomena, it was possible to measure morphological priming effects for prefixed and suffixed forms on the same targets, which allowed for direct comparisons of priming effects from the two types of derived words (prefixation, suffixation) for both –R and +R affixes. Example 1 illustrates a stimulus set in the morphological priming conditions. In addition, we included orthographic priming conditions, with both word-initial and word-final overlap, as shown in Example 2, and a semantic priming condition, as shown in Example 3.

Example 1. Morphological priming

(–R) *unsauber—sauber*	*Sauberkeit—sauber*
“not clean”—“clean”	“cleanness”—“clean”
(+R) *inaktiv—aktiv*	*Aktivität—aktiv*
“inactive”—“active”	“activity”—“active”

Example 2. Orthographic priming

Tutor—Tor	*Tortur—Tor*
“tutor”—“gate/goal”	“torture”—“gate/goal”

Example 3. Semantic priming

Herd—Pfanne
“stove”—“pan”

If morphological decomposition in a L2 works less efficiently, L2 speakers should show smaller priming effects than L1 speakers. Furthermore, if prefixed words are only decomposed postlexically, they should yield reduced priming effects compared to suffixed words. Likewise, if lexical restrictedness reduces decomposability, lexically restricted forms (+R) should yield smaller masked priming effects than (–R) forms.

Method

Participants

Forty-eight L1 speakers (37 women) and 48 L2 speakers (43 women) of German took part in the experiment in exchange for payment or course credits. Participants in the two groups had similar ages ($M_{\text{age L1}}$ = 25.46 years, *SD* = 4.13, *range* = 18–34; $M_{\text{age L2}}$ = 26.04 years, *SD* = 4.82, *range* = 20–41), and levels of education ranging from high school diploma to university degrees (L1: 28 high school, 1 vocational training, 19 university degree; L2: 14 high school, 34 university degree). All participants in the L2 group were native speakers of Russian; eight of them spoke Ukrainian (7) or Azerbaijani (1) as their additional mother tongue. They all learned German after the age of 6 (M_{age} = 13.02 years, *SD* = 5.46, *range* = 6–24), 20 of them as their first foreign language (two of which simultaneously with another language), 27 as their second foreign language, and one as her fifth language. They all lived in Germany at the time of testing, having arrived in Germany at a mean age of 18.94 years (*SD* = 6.81, *range* = 7–35), and reported using German, both written and spoken, on a regular basis, with a mean use of written German of 50.6% (*SD* = 21.3, *range* = 6–95) and a mean use of spoken German of 50.3% (*SD* = 19.7, *range* = 13–95). The L2 participants’ skills in German were assessed using a 30-item multiple-choice test developed by the Goethe

Institute (https://www.goethe.de/de/spr/kup/prf/prf.html). Only participants who achieved a score corresponding to the levels B2, C1, or C2 of the Common European Framework of Reference for Languages (Verhelst, Van Avermaet, Takala, Figueras, & North, 2009) were recruited for the study. B2 represents the upper rank of the so-called "independent user" level, and C1 and C2 refer to the two ranks of the "proficient user" level. The L2 group achieved a mean score of 25.31/30 (*SD* = 3.07, *range* = 19–30), corresponding to a mean level of C1 (*range* = B2–C2).

Materials

Critical Items

We selected all items, together with their (base 10 log-transformed) lemma and word form frequency per million, from the webCELEX database (http://celex.mpi.nl). Tables 1 and 2 provide prime and target characteristics for all experimental sets. Following Sassenhagen and Alday's (2016) suggestion, these tables report information about matching for the selected variables through descriptive rather than inferential statistics.[1] A complete list of the stimuli is available in Appendix S1 in the Supporting Information online.

Morphological priming was tested with both lexically unrestricted (–R) and lexically restricted (+R) affixes. For the –R set, we extracted from the webCELEX database adjectives that permit both a negated derived form with the prefix *un–* and a derived nominalization with the suffix *–keit*. Similarly, for the +R set, we extracted adjectives from the database that permit both a negated prefixed derivation with the prefix *in–* and a suffixed nominalization with *–ität*. In this way, we ensured that prefixation and suffixation priming effects were measured on the same stems. The 12 targets in the –R set were thus paired with three types of primes: (a) a negated adjective with the prefix *un–*, (b) a deadjectival noun with the suffix *–keit*, and (c) a matched unrelated control prime. Unrelated primes were dissimilar in form or meaning to their corresponding targets. Half of the unrelated primes were nouns and half were adjectives. All primes were matched as closely as possible for lemma and word form frequency and for number of syllables. Similarly, the 12 targets of the lexically restricted set (+R) were paired with a prefixed (*in–*), a suffixed (*–ität*), and an unrelated prime. All primes were matched for lemma and word form frequency; matching in terms of number of syllables was not possible for the +R items, as *–ität* is bisyllabic and *in–* monosyllabic. There were 72 prime–target pairs in the two morphological sets (–R, +R) for each list, with 12 pairs for each of the three prime types.

Table 1 Characteristics of primes in each set

Set/Prime type	Statistic	LF	WFF	Letters	Syllables	Overlap
–R/Prefixed	*M* (*SD*)	0.22 (0.33)	0.13 (0.26)	9.75 (1.48)	3.17 (0.39)	0.90 (0.02)
	95% CI	[0.01, 0.43]	[–0.03, 0.30]	[8.81, 10.69]	[2.92, 3.41]	[0.89, 0.91]
–R/Suffixed	*M* (*SD*)	0.26 (0.35)	0.26 (0.35)	11.75 (1.48)	3.42 (0.51)	0.90 (0.02)
	95% CI	[0.04, 0.48]	[0.04, 0.48]	[10.81, 12.69]	[3.09, 3.74]	[0.89, 0.91]
–R/Unrelated	*M* (*SD*)	0.28 (0.37)	0.14 (0.27)	9.58 (1.16)	3.50 (0.52)	–
	95% CI	[0.04, 0.51]	[–0.04, 0.31]	[8.84, 10.32]	[3.17, 3.83]	–
+R/Prefixed	*M* (*SD*)	0.00 (0.00)	0.00 (0.00)	9.25 (1.48)	3.75 (0.62)	0.89 (0.02)
	95% CI	[0.00, 0.00]	[0.00, 0.00]	[8.31, 10.19]	[3.36, 4.14]	[0.88, 0.90]
+R/Suffixed	*M* (*SD*)	0.45 (0.57)	0.45 (0.55)	11.25 (1.48)	4.75 (0.62)	0.85 (0.06)
	95% CI	[0.09, 0.82]	[0.09, 0.80]	[10.31, 12.19]	[4.36, 5.14]	[0.81, 0.89]
+R/Unrelated	*M* (*SD*)	0.36 (0.46)	0.22 (0.37)	9.67 (1.61)	3.92 (0.67)	–
	95% CI	[0.07, 0.66]	[–0.02, 0.46]	[8.64, 10.69]	[3.49, 4.34]	–
Orthographic/Word final	*M* (*SD*)	0.36 (0.60)	0.27 (0.47)	6.50 (1.00)	2.00 (0.43)	0.87 (0.08)
	95% CI	[–0.01, 0.74]	[–0.03, 0.58]	[5.86, 7.14]	[1.73, 2.27]	[0.82, 0.92]
Orthographic/Word initial	*M* (*SD*)	0.97 (0.57)	0.80 (0.59)	6.50 (1.51)	2.33 (0.78)	0.87 (0.08)
	95% CI	[0.6, 1.33]	[0.42, 1.17]	[5.54, 7.46]	[1.84, 2.83]	[0.81, 0.92]
Orthographic/Unrelated	*M* (*SD*)	0.66 (0.54)	0.43 (0.53)	6.42 (1.24)	2.33 (0.49)	–
	95% CI	[0.32, 1.00]	[0.10, 0.77]	[5.63, 7.2]	[2.02, 2.65]	–
Semantic/Related	*M* (*SD*)	0.96 (0.58)	0.67 (0.52)	5.89 (1.69)	1.89 (0.60)	–
	95% CI	[0.52, 1.41]	[0.28, 1.07]	[4.59, 7.19]	[1.43, 2.35]	–
Semantic/Unrelated	*M* (*SD*)	0.71 (0.48)	0.42 (0.37)	6.33 (1.50)	2.11 (0.78)	–
	95% CI	[0.34, 1.08]	[0.14, 0.70]	[5.18, 7.49]	[1.51, 2.71]	–

Note. LF = lemma frequency; WFF = word form frequency; Overlap = orthographic overlap between prime and target.

Table 2 Characteristics of targets in each set

Set	Statistic	LF	WFF	Letters	Syllables
–R	*M* (*SD*)	0.83 (0.44)	0.44 (0.48)	7.75 (1.48)	2.17 (0.39)
	95% CI	[0.55, 1.11]	[0.13, 0.74]	[6.81, 8.69]	[1.92, 2.41]
+R	*M* (*SD*)	0.68 (0.57)	0.36 (0.52)	7.25 (1.48)	2.75 (0.62)
	95% CI	[0.32, 1.05]	[0.03, 0.69]	[6.31, 8.19]	[2.36, 3.14]
Orthographic	*M* (*SD*)	1.23 (0.50)	0.97 (0.52)	3.58 (0.79)	1.08 (0.29)
	95% CI	[0.92, 1.55]	[0.64, 1.30]	[3.17, 4.16]	[0.90, 1.27]
Semantic	*M* (*SD*)	0.96 (0.58)	0.67 (0.52)	5.56 (1.13)	1.89 (0.60)
	95% CI	[0.52, 1.41]	[0.28, 1.07]	[4.69, 6.42]	[1.43, 2.35]

Note. LF = lemma frequency; WFF = word form frequency.

The items selected for the two sets (–R vs. +R) were matched as closely as possible to allow for comparisons between them. The targets for the two sets had similar word form frequencies, lemma frequencies, and length. Because foreign words (for the –R condition) are typically longer than native German words, we decided to include some targets in the –R set that are morphologically complex. However, care was taken to ensure that none of the selected target words incurred any bracketing paradoxes (e.g., Spencer, 1988). Consider, for example, the target *gastlich* "hospitable" derived from the noun *Gast* "guest." In this case, *un–* can be attached to the derived adjective *gastlich* but not to *Gast*, hence bypassing a bracketing paradox. Furthermore, the different primes (prefixed, suffixed, unrelated) were held as parallel as possible in the two sets (±R) in terms of length and frequency.

Control Items

We additionally created two control sets to determine to what extent priming effects for the two morphological sets are due to orthographic or semantic prime–target overlap. As in the morphological sets, the 12 target words of the orthographic set are orthographically fully contained in their related primes. To create this set, we selected from the webCELEX database pairs of simple words overlapping orthographically, but not morphologically or semantically, so that the target word was fully embedded in the prime word (similar to the morphologically related pairs). Each target was combined with an unrelated prime and two related primes, one in which the targets were embedded word finally and one in which they were embedded word initially, mimicking the prefixed and suffixed prime–target pairs from the morphological sets (e.g., *Tortur–Tor* "torture–gate/goal" and *Tutor–Tor* "tutor–gate/goal"). There were

12 prime–target pairs for each type of prime in each list. Targets and primes of the orthographic set were nouns and adjectives, and all primes were matched for lemma and word form frequency as well as number of letters and syllables.

For all related prime–target pairs in the morphological and orthographic sets, we computed the prime–target orthographic overlap ratio by using the Spatial Coding option in Davis's (2000) Match Calculator. The prefixed and suffixed primes in the –R set had the same amount of overlap to their target despite being different in length (see Table 1) because, in both cases, the prime fully contained the target, which is what this measure captures. The same is true for word-initial and word-final orthographically overlapping prime–target pairs while, in the case of +R items, the overlap was slightly lower for the suffixed primes because four of them contained a letter change in the stem (e.g., *Flexibilität* "flexibility"–*flexibel* "flexible"). Although it was not possible to select items in the orthographic set that were matched in length to the corresponding items in the morphological sets (because longer words in German tend to be morphologically complex), the pairs in the morphological and orthographic sets were matched for orthographic overlap. Furthermore, targets as well as related and unrelated primes were selected from a similar frequency range as those in the morphological sets.

For the semantic control set, we selected semantically related prime–target pairs that were morphologically unrelated, but were instead semantic associates and antonyms, thus mimicking the semantic relationships between suffixed prime–target pairs and between prefixed prime–target pairs (e.g., *Herd–Pfanne* "stove–pan," *fleißig–faul* "diligent–lazy"). The targets in the semantic set were as closely matched as possible to those of the two morphological sets in terms of lemma and word form frequency. The semantically related and unrelated primes were matched to each other for lemma and word form frequency and length in syllables and letters. There were 12 prime–target pairs each for two prime types (related, unrelated).[2] As a semantic relatedness measure, we conducted an online survey in which 30 native speakers of German rated both the related and the unrelated prime–target pairs with respect to how similar in meaning the two words are on a 1–7 scale (with 1 as the lowest degree of similarity). The survey confirmed that each semantically related pair received a higher semantic similarity rating ($M = 4.62$, $SD = 1.08$) than its corresponding semantically unrelated pair ($M = 1.29$, $SD = 0.14$).

Experimental Lists

Experimental lists were created following a Latin Square design. There were three blocks of items such that each block contained each target from the morphological and orthographic sets with a different prime type (prefixed/word-final overlap, suffixed/word-initial, unrelated). Targets from the semantic control set were distributed over two of these three blocks, as this set had only two prime types (related, unrelated). We then constructed three experimental lists, each with a different order of blocks, to control for effects of presentation order of each target with a specific prime. We finally created three additional lists with the reversed item order—to counterbalance for training or fatigue effects—resulting in six experimental lists in total.

The 132 experimental prime–target pairs in each list were mixed with 468 unrelated prime–target filler pairs, for a total of 600 trials. All trials were distributed across the lists in a pseudorandomized order, with three to five fillers occurring between two successive experimental targets. Of the fillers, 300 were nonwords, so that "no" responses were required in half of the trials. Nonwords were created replacing one to three graphemes of existing German words. Adjectives, nouns, verbs, and adverbs were evenly distributed across the fillers. In total, 13.83% of all trials in each list consisted of related prime–target pairs.

Procedure

We tested all participants in a quiet laboratory room and randomly assigned them to one of the six presentation lists. Participants' reaction times (RTs) in milliseconds were measured using the experimental software DMDX (Forster & Forster, 2003). Participants were informed that they would see a sequence of existing German words and invented words in the center of the computer screen, and that they would have to decide as quickly and accurately as possible whether or not the target word was an existing word of German. The lexical decisions were performed by pressing one of two different buttons on a gamepad connected to the computer. "Yes" responses were always elicited with the participants' dominant hand. Each trial started with a 500-millisecond blank screen. This was followed by a forward mask consisting of a number of hashes equal to the number of letters of the prime. Next, the prime was presented for 50 milliseconds, directly followed by the target. The target was displayed until the participant pressed the yes or no button, or otherwise disappeared after 500 milliseconds, with the screen turning blank. The maximum time allowed for the lexical decision was 5,000 milliseconds after presentation of the target. The next trial began right after the lexical decision, or after the (5 second) timeout.

Data Analysis

The experiment yielded accuracy and RT data. The accuracy data were analyzed using a binary logistic regression model. For the RT data, timeouts and incorrect responses were excluded from all subsequent analyses (L1 = 4.91%, L2 = 7.75% of the experimental items). The remaining RT data were then log-transformed to normalize their distribution and reduce the influence of outliers (Ratcliff, 1993). Responses above and below two and a half standard deviations from each participant mean log RT across all correct trials were considered outliers and therefore also removed (L1 = 1.01%, L2 = 0.95% of the remaining experimental items). The log RT data were then analyzed in a series of mixed-effect linear regression models using the software R (Version 3.3.2; R Core Team, 2014).

All models were fitted using the package lme4 (Bates, Mächler, Bolker, & Walker, 2015). Parameters were estimated with restricted maximum likelihood. Depending on what a given model was supposed to test, a combination of the factors Group (L1, L2), Set (+R, –R), Relatedness Type (morphological, orthographic, semantic), Prime Type (e.g., prefixed, suffixed, unrelated), and their interactions were included as fixed effects. All contrasts for these fixed effects were computed from the generalized inverse function (Schad, Hohenstein, Vasishth, & Kliegl, 2018) so that the models would show main effects for each of the levels (e.g., prefixed Prime Type) across, for example, different sets or groups as compared to the level that was selected as baseline. All models included random intercepts for subjects and targets. For each analysis, we selected the best-fit model by adopting a bottom-up approach, starting from an intercept-only model. The initial model was expanded stepwise, by testing for inclusion of the following additional (centered) continuous predictors: (a) Block, to account for repetition effects of the targets (coded as 1–3 for the morphological and orthographic sets and as 1–2 for the semantic set, because targets were only repeated twice); (b) Prime Letters, to account for the consistently different length of the primes (in letters) across prime types and sets; and (c) Skill in German as interacting with Prime Type (in the models including only L2 speakers), to test whether the priming effects found for this group were modulated by the speakers' skill of L2 German (as measured through the Goethe Institute test). Additional fixed effects were only included if they significantly improved the model fit, as tested by the R anova function comparing the models with and without the additional predictor, with parameters being estimated for maximum likelihood.

Once we determined the best fixed-effect structure for each model, we then tested stepwise for inclusion of random slopes by subjects and targets

Table 3 Mean RTs (standard deviations in parentheses) in milliseconds and (percent correct) accuracy scores for the L1 group

	Morphological			
Priming	–R	+R	Orthographic	Semantic
Prime type	Unrelated		Unrelated	Unrelated
RT	625 (133)	631 (138)	582 (118)	600 (118)
Accuracy	93.06%	87.85%	98.26%	98.15%
Prime Type	Suffixed		Word initial	Related
RT	600 (132)	604 (142)	569 (125)	594 (134)
Priming effect	25	27	13	6
Accuracy	95.83%	92.88%	97.74%	97.22%
Prime type	Prefixed		Word final	
RT	610 (152)	614 (147)	581 (129)	
Priming effect	15	17	1	
Accuracy	97.92%	90.45%	97.92%	

for each fixed effect contained in the model, following the same procedure as that described for the fixed effects (Baayen, 2008, 2014; Matuschek, Kliegl, Vasishth, Baayen, & Bates, 2017). If more than one random slope significantly improved the model fit, we first selected the model with the lowest Akaike Information Criterion (AIC) and then proceeded with testing for inclusion of additional slopes. In the Results section, we report the fixed and random effects structure for the best-fit model computed in each analysis.[3]

Results

Overall Patterns

Tables 3 and 4 provide mean RTs and accuracy scores for lexical decisions to targets, separately for each set and prime type in the L1 and L2 groups. In terms of the accuracy data, we first noted very high accuracy scores of more than 95% correct responses in the orthographic and semantic sets for all prime types and for both participant groups. We therefore did not perform any further analyses on these accuracy scores. The two morphological sets, on the other hand, yielded slightly reduced accuracy scores in all conditions for the L2 (relative to the L1) participants. Furthermore, the two morphological sets had higher accuracy scores following related primes than unrelated primes. Finally, responses were more accurate with targets in the –R than with targets in the +R set.

Table 4 Mean RTs (standard deviations in parentheses) in milliseconds and (percent correct) accuracy scores for the L2 group

	Morphological			
Priming	–R	+R	Orthographic	Semantic
Prime type	Unrelated		Unrelated	Unrelated
RT	754 (211)	716 (209)	654 (184)	677 (175)
Accuracy	89.06%	85.94%	97.22%	95.60%
Prime Type	Suffixed		Word initial	Related
RT	732 (232)	689 (214)	648 (202)	677 (162)
Priming effect	22	27	6	0
Accuracy	90.62%	89.93%	96.88%	95.83%
Prime type	Prefixed		Word final	
RT	716 (210)	699 (233)	640 (166)	
Priming effect	38	17	14	
Accuracy	91.32%	88.37%	95.66%	

To analyze these data statistically, we fitted a binary logistic regression model to the accuracy data from the two morphological sets that included the fixed factors Group (L1, L2), Set (+R, –R), and Prime Type (prefixed, suffixed, unrelated). The best-fit model revealed a significant main effect of Prime Type (prefixed: $b = 0.585$, $SE = 0.122$, $z = 4.804$; suffixed: $b = 0.526$, $SE = 0.121$, $z = 4.334$). These results confirmed that target accuracy was higher for both prefixed and suffixed primes (relative to unrelated primes). In contrast, we did not find a main effect of Group (L1 vs. L2: $b = 0.287$, $SE = 0.298$, $z = 0.962$) or Set ($b = 0.312$, $SE = 0.606$, $z = 0.515$).

With regard to the RT data, Tables 3 and 4 show overall longer RTs for the L2 than the L1 participants. Secondly, the two morphological sets yielded considerable facilitation in both participant groups (L1, L2) for both prefixed and suffixed words as well as for both lexically restricted and unrestricted affixes (±R). Thirdly, the orthographic and semantic sets yielded small tendencies toward facilitation with some of the prime types, but facilitation from morphological primes was always numerically larger than that from orthographic or semantic primes. To analyze these data statistically, we fitted a number of mixed-effect linear regression models to the RT data.

Table 5 Fixed effects for the overall model of the two morphological sets (± R)

Fixed effects	Estimate	*SE*	*t*
(Intercept)	6.4777	0.0256	253.315*
Prime Type (suffixed vs. unrelated)	–0.0492	0.0068	–7.261*
Prime Type (prefixed vs. unrelated)	–0.0378	0.0054	–7.013*
Group (L1 vs. L2) × Prime Type (suffixed vs. unrelated)	–0.0077	0.0104	–0.739
Group (L1 vs. L2) × Prime Type (prefixed vs. unrelated)	0.0107	0.0107	–1.004
Set (–R vs. +R) × Prime Type (suffixed vs. unrelated)	0.0006	0.0101	0.056
Set (–R vs. +R) × Prime Type (prefixed vs. unrelated)	–0.0114	0.0100	–1.132
Group (L1 vs. L2) × Set (–R vs. +R) × Prime Type (suffixed vs. unrelated)	0.0045	0.0200	0.225
Group (L1 vs. L2) × Set (–R vs. +R) × Prime Type (prefixed vs. unrelated)	0.0260	0.0200	1.302

*Formula in R: log (RT) ~ Group * Set * Prime Type + Block + Prime Letters + (1 + Prime Type + Block + Prime Letters | subject) + (1 + Group + Block | target)*

Note. $^{*}p < .05$.

Morphological Priming

Our main analysis tested morphological priming for different types of derived words (prefixed and suffixed, –R and +R) and groups of speakers (L1 and L2). The best-fit model (Table 5) included fixed effects for Group (L1, L2), Set (–R, +R), and Prime Type (suffixed, prefixed, unrelated) and their interactions, as well as the centered covariates Block and Prime Letters, because they both improved the model fit. The effect of Block on RTs was significant ($b = –0.049$, $SE = 0.004$, $t = –11.800$) while the effect of Prime Letters was not ($b = 0.011$, $SE = 0.006$, $t = 1.682$). The model revealed significant main effects of Prime Type for both prefixed and suffixed primes (both $|t|$s > 7.013). In contrast, none of the interactions involving Group, Set, and Prime Type were significant (all $|t|$s < 1.302). By changing the baseline for the factor Prime Type to “prefixed,” we directly compared prefixation to suffixation priming. No significant difference was found ($b = –0.011$, $SE = 0.0072$, $t = –1.597$).

The results from the above model yielded similar outcomes for prefixed and suffixed words, for both –R and +R forms, and for the two participant groups. However, a lack of a three-way interaction could be due to lack of power and

Table 6 Fixed effects for models split by group and set (± R)

Fixed effects	Estimate	*SE*	*t*
L1 Group, –R Set			
(Intercept)	6.3982	0.0263	243.004*
Prime Type (suffixed vs. unrelated)	–0.0442	0.0087	–5.092*
Prime Type (prefixed vs. unrelated)	–0.0321	0.0086	–3.730*
Formula in R: log (RT) ~ Prime Type + Block + (1 + Block | subject) + (1 | target)			
L1 Group, +R Set			
(Intercept)	6.4194	0.0308	208.662*
Prime Type (suffixed vs. unrelated)	–0.0527	0.0159	–3.323*
Prime Type (prefixed vs. unrelated)	–0.0426	0.0150	–2.836*
Formula in R: log (RT) ~ Prime Type + Block + (1 + Block | subject) + (1 + Prime Type | target)			
L2 Group, –R Set			
(Intercept)	6.5797	0.0410	160.570*
Prime Type (suffixed vs. unrelated)	–0.0361	0.0112	–3.225*
Prime Type (prefixed vs. unrelated)	–0.0544	0.0112	–4.859*
Formula in R: log (RT) ~ Prime Type + Block + (1 + Block | subject) + (1 | target)			
L2 Group, +R Set			
(Intercept)	6.5433	0.0441	148.436*
Prime Type (suffixed vs. unrelated)	–0.0382	0.0111	–3.428*
Prime Type (prefixed vs. unrelated)	–0.0330	0.0112	–2.951*
Formula in R: log (RT) ~ Prime Type + Block + (1 | subject) + (1 + Block | target)			

Note. $^{*}p < .05$.

does not necessarily mean that the priming effects for the two morphological types, the two item sets, and the two participant groups were all reliable. To test whether this was the case, we ran four additional linear-mixed effect models separately for each set and group. All models included Prime Type as fixed effect plus the covariate Block, as this significantly improved the model fit. The results from the best-fit models, as well as their formulas, are provided in Table 6, where it can be seen that all morphological priming effects proved to be significant. Furthermore, by back-transforming the estimates from the models into raw RTs, we computed the size of each morphological priming effect as estimated by the statistical models. For L1 speakers, the estimated priming

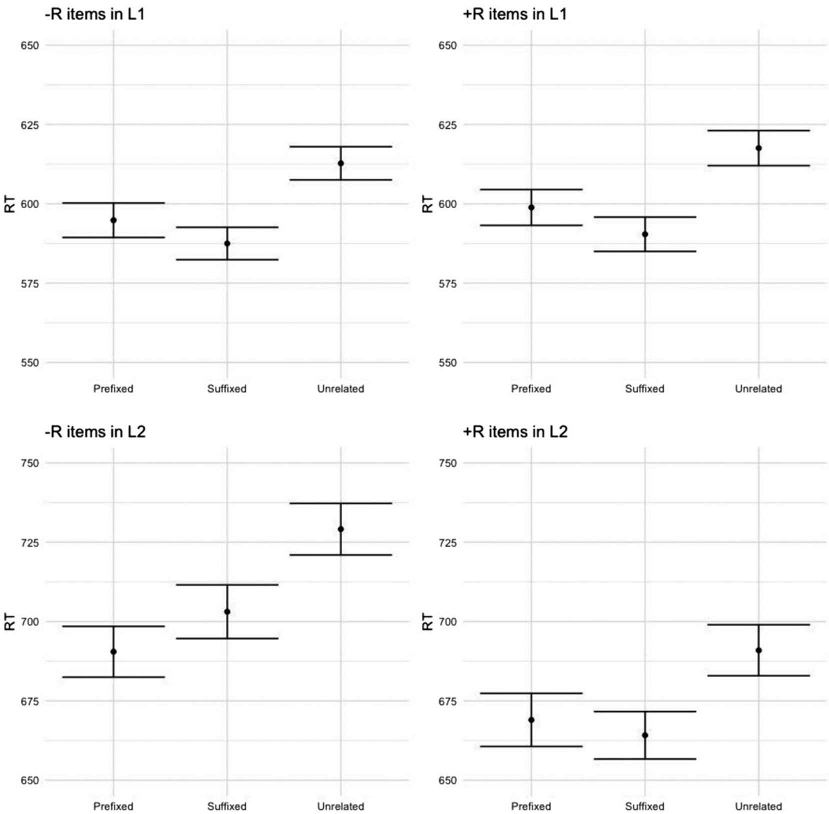

Figure 1 Back-transformed log RTs and SEs for the two morphological sets (+R, –R) in the two participant groups (L1, L2).

effect for –R items was 26 milliseconds for suffixed primes and 19 milliseconds for prefixed primes; the effect for +R items was 32 milliseconds for suffixed primes and 26 milliseconds for prefixed primes. For the L2 group, –R items showed an estimated priming effect of 26 milliseconds with suffixed primes and 38 milliseconds with prefixed primes; +R items showed an estimated priming effect of 26 milliseconds with suffixed primes and 23 milliseconds with prefixed primes. Overall, our results from the morphological sets indicate significant derivational priming for both prefixed and suffixed words, lexically restricted and unrestricted primes, and for both L1 and L2 speakers.[4] These results are graphically illustrated in Figure 1.

Additional Analyses

The purpose of the additional analyses was to compare the morphological priming effects to the magnitudes of orthographic and semantic priming effects. The results are provided in Table 7. In terms of morphological versus orthographic priming, for this comparison, both prefixed and word-final (orthographic) overlap primes were labeled “word final,” while both suffixed and word-initial (orthographic) overlap primes were labeled “word initial.” The best-fit model included the fixed factors of Group (L1, L2), Relatedness Type (morphological, orthographic), and Prime Type (word initial, word final, unrelated), their interactions, and the covariates Block and Prime Letters, which both improved model fit and had a significant effect on RTs (Block: $b = -0.049$, $SE = 0.004$, $t = -12.684$; Prime Letters: $b = 0.012$, $SE = 0.005$, $t = 2.212$). As shown in Table 7, the model revealed significant two-way interactions for the two participant groups between Relatedness Type and Prime Type for both word-final and word-initial prime types (both $|t|$s > 3.267), which were due to larger suffixation than word-initial orthographic priming and larger prefixation than word-final orthographic priming. There were no significant three-way interactions between Group, Relatedness Type, and Prime Type or two-way interactions between Group and Prime Type.

With regard to morphological versus semantic priming, the semantic set only included two Prime Types (related, unrelated), while the morphological sets contained three Prime Types (prefixed, suffixed, unrelated). We therefore had to perform two separate analyses, one comparing prefixation priming to semantic priming (prefixed/related prime, unrelated prime) and one comparing suffixation priming to semantic priming (suffixed/related prime, unrelated prime). Both models contained the fixed factors Group (L1, L2), Relatedness Type (morphological vs. semantic) and Prime Type (related, unrelated) and their interactions, together with Block, as it improved model fit and had a significant effect on RTs in both models (both $|t|$s > 11). As shown in Table 7, both models yielded significant two-way interactions between Relatedness Type and Prime Type (in both models, $|t|$s > 2.811) due to larger morphological than semantic priming. The three-way interactions with Group (L1, L2) were not significant (in both models, $|t|$s < 1.276). Overall, the additional analyses focusing on the control item sets indicated that the morphological priming effects reported in Tables 5 and 6 for both L1 and L2 speakers and for all the different types of derived words cannot be attributed to orthographic or semantic prime–target overlap.

Table 7 Fixed effects from the models testing morphological versus orthographic priming and morphological versus semantic priming

Fixed effects	Estimate	*SE*	*t*
Morphological vs. orthographic priming			
(Intercept)	6.4406	0.0203	317.897*
Prime Type (word initial vs. unrelated)	–0.0344	0.0045	–7.570*
Prime Type (word final vs. unrelated)	–0.0241	0.0042	–5.800*
Group (L1 vs. L2) × Prime Type (word initial vs. unrelated)	–0.0089	0.0084	–1.059
Group (L1 vs. L2) × Prime Type (word final vs. unrelated)	0.0119	0.0083	1.430
Relatedness (morphological vs. orthographic) × Prime Type (word initial vs. unrelated)	–0.0303	0.0090	–3.378*
Relatedness (morphological vs. orthographic) × Prime Type (word final vs. unrelated)	–0.0272	0.0083	–3.267*
Group (L1 vs. L2) × Relatedness (morphological vs. orthographic) × Prime Type (word initial vs. unrelated)	–0.0003	0.0168	0.018
Group (L1 vs. L2) × Relatedness (morphological vs. orthographic) × Prime Type (word final vs. unrelated)	–0.0033	0.0166	–0.202
*Formula in R: log (RT) ~ Group * Relatedness Type * Prime Type + Block + Prime Letters + (1 + Set + Block + Prime Letters | subject) + (1 + Group + Block | target)*			
Suffixation vs. semantic priming			
(Intercept)	6.4426	0.0218	295.265*
Prime Type (related vs. unrelated)	–0.0250	0.0060	–4.199*
Group (L1 vs. L2) × Prime Type (related vs. unrelated)	–0.0095	0.0090	–1.056
Relatedness (morphological vs. semantic) × Prime Type (related vs. unrelated)	–0.0334	0.0119	–2.811*
Group (L1 vs. L2) × Relatedness (morphological vs. semantic) × Prime Type (related vs. unrelated)	0.0026	0.0180	0.144
*Formula in R: log (RT) ~ Group * Relatedness Type * Prime Type + Block + (1 + Relatedness Type + Block | subject) + (1 + Group + Prime Type + Block | target)*			
Prefixation vs. semantic priming			
(Intercept)	6.4478	0.0220	292.858*
Prime Type (related vs. unrelated)	–0.0233	0.0046	–5.089*
Group (L1 vs. L2) × Prime Type (related vs. unrelated)	–0.0013	0.0092	–0.137

(*Continued*)

Table 7 Continued

Fixed effects	Estimate	*SE*	*t*
Relatedness (morphological vs. semantic) × Prime Type (related vs. unrelated)	–0.0320	0.0091	–3.502*
Group (L1 vs. L2) × Relatedness (morphological vs. semantic) × Prime Type (related vs. unrelated)	0.0233	0.0183	1.276

*Formula in R: log (RT) ~ Group * Relatedness Type * Prime Type + Block + (1 + Relatedness Type + Block | subject) + (1 + Group + Block | target)*

Note. $^{*}p < .05$.

Discussion

Summary of Findings

In the present study, we found significant morphological priming effects for both L1 and L2 speakers of German and for different types of derived words. This finding is in line with results from previous masked priming studies for (suffixed) derived word forms in a variety of languages, including English (Silva & Clahsen, 2008), German (Jacob et al., 2018), Turkish (Kirkici & Clahsen, 2013), and extends them to derivation by prefixation. Furthermore, in line with previous L1 research, morphological priming in both L1 and L2 speakers was clearly dissociable from facilitation due to orthographic or semantic prime–target overlap (Rastle et al., 2000).

Previous (L1) masked priming studies reported significant priming effects for both suffixed and prefixed word forms (Diependaele et al., 2009; Forster & Azuma, 2000; Grainger et al., 1991; Heide et al., 2010; Kim et al., 2015). However, while these earlier results come from different experiments with different target words and different participants, precluding any direct comparisons of priming magnitudes, the current study was specifically designed to measure priming with existing prefixed and suffixed word forms using the same targets and within the same participants. We found significant priming effects with both prefixed and suffixed words. This finding indicates efficient morphological decomposition for both prefixed words and suffixed words, which seems to contradict claims made in the literature that prefixed words might be less susceptible to decomposition than suffixed ones (Beauvillain, 1996; Bergman et al., 1988; Colé et al., 1989; Ferrari Bridgers & Kacinik, 2017). However, all these prior studies have employed experimental techniques in which stimuli were overtly presented for lexical decision, which may explain why these studies yielded different results from the masked priming experiments testing existing prefixed words (Diependaele et al., 2009; Forster & Azuma, 2000; Grainger et al., 1991; Heide et al., 2010; Kim et al., 2015). While masked priming is supposed to tap into early prelexical stages of visual word recognition (Marslen-Wilson, 2007), RTs from overtly presented stimuli also include later processes of lexical retrieval. Hence, these latter techniques are less likely to detect processes of (prelexical) morphological decomposition than masked priming. Another finding from our study is that derived word forms with both lexically restricted and unrestricted affixes yielded significant masked priming effects, replicating previous results from Silva and Clahsen (2008) on *–ness* and *–ity* nominalizations in English and extending them to prefixed words.

Mechanisms of Morphological Decomposition

The priming effects that we obtained for derived word forms are consistent with different accounts of morphological processing during reading: (a) affix stripping (Rastle & Davis, 2008), (b) morphemic decomposition (Stockall & Marantz, 2006), and (c) edge-aligned embedded word activation (Grainger & Beyersmann, 2017).

Affix stripping, originally proposed by Taft and Forster (1975) and further developed in recent research (Amenta & Crepaldi, 2012; Rastle & Davis, 2008), is conceived of as a general mechanism of visual word recognition that is sensitive to the surface form of a morphologically complex word and is supposed to apply to all kinds of affixed word forms. In our case, affixes are stripped off from word forms such as *unsauber*, *inaktiv*, *Sauberkeit*, and *Aktivität*, by which the prime words' corresponding stems are isolated, thereby facilitating the subsequent recognition of the related target words *sauber* and *aktiv*, respectively. The morphemic decomposition account (e.g., Gwilliams & Marantz, 2018; Stockall & Marantz, 2006) holds that the recognition system exhaustively decomposes all morphologically complex words into their basic morphemes according to the grammatical rules of the language. As the items we tested are fully parsable into their morphemes, the priming effects obtained are consistent with this account. Finally, according to Grainger and Beyersmann's (2017) account, embedded words (rather than affixes or morphemes) represent the primary reading units, with embedded words proposed to be activated at both edges of the letter string. This account applies to derived words such as *unsauber* and *Sauberkeit* with the embedded word *sauber*, the activation of which may cause a priming effect on the target word *sauber*.

These three accounts can only partially explain the experimental findings from the current morphological processing literature, especially if we include evidence from both L1 and L2 speakers and if we consider different types of morphologically complex words. What matters for affix stripping, morphemic decomposition, and embedded word activation is the presence of segmentable affixes/morphemes/words, irrespective of whether the complex word is the result of derivation, compounding, or inflection. However, several studies have revealed some degree of variability as to how these supposedly ubiquitous mechanisms apply, particularly for inflection.

It is true that compounds have yielded robust and stable priming effects across different morphological types and speaker groups in a number of previous studies, similar to what we found for derived word forms. Masked priming studies, for example, revealed efficient priming effects for both the head and the modifier components of compounds, and for both transparent and opaque compounds (Beyersmann et al., 2018; Duñabeitia, Laka, Perea, & Carreiras, 2009; Fiorentino & Fund-Reznicek, 2009). Furthermore, studies comparing L1 and proficient L2 speakers found similar effects of decomposition of compounds for both speaker groups (González Alonso, Baquero Castellanos, & Müller, 2016; M. Li et al., 2017; Uygun & Gürel, 2017). Priming studies of inflection, on the other hand, have led to more variable outcomes. For L1 speakers, morphological priming effects indicative of stem–affix decomposition were found to be reduced for irregular (relative to regular) inflected words, even for irregular forms that have segmentable affixes/morphemes (Jacob, Fleischhauer, & Clahsen, 2013; Neubauer & Clahsen, 2009; Sonnenstuhl, Eisenbeiss, & Clahsen, 1999). For L2 speakers, a number of masked priming studies that directly compared derivation and inflection (Jacob et al., 2018; Kirkici & Clahsen, 2013; Silva & Clahsen, 2008) found efficient priming effects for derivation, but reduced or no priming for regular inflection in the same speakers. In contrast, other L2 studies reported significant priming effects for inflected words (Feldman et al., 2010; Foote, 2017). Models of morphological processing should be able to capture both the consistency and variability of the decomposition mechanism for different linguistic morphological types and speaker groups. In the following, we offer a few (admittedly speculative) thoughts of how this could be achieved.

From a linguistic perspective, derivation and compounding have much in common. Both are word formation processes as opposed to inflectional or paradigmatic processes (for a review, see Spencer, 1991). Item-and-arrangement accounts of morphology (Lieber, 1992; Selkirk, 1986) particularly stress the similarities between compounding and derivation, in that the difference between compounding and derivation is supposed to reduce to one property, namely, that derivational morphemes are subcategorized as only appearing in combination with a stem. Apart from that, the component parts of compounds and derived words are lexical items with their own form and meaning properties. Unlike word formation processes, inflectional processes do not yield any new lexical entries, but are instead feature–form mappings that specify the form that realizes or spells out a particular set of features. An inflected word form such as *builds*, for example, is the result of an inflectional rule that spells out the morphosyntactic feature set (3rd person, singular, present, indicative) by adding the exponent /s/ to the base verb "build" (Anderson, 1992; Matthews, 1991; Stump, 2001).

These linguistic considerations help to better understand the priming results. Suppose a principle of full decomposition, according to which recognition and lexical access are facilitated when the whole letter string can be completely divided into its basic lexemes. Grainger and Beyersmann (2017) originally posited this principle for embedded words to explain why compounds such as *teacup* and *honeymoon* effectively prime their respective base words, whereas this is not the case for words such as *window* or *carpet* for which full decomposition fails. We suggest to extend the principle of full decomposition to embedded lexemes. Assuming that derivational morphemes are indeed lexemes (Lieber, 1992), full decomposition then applies to both compounds and derived words and provides a boost in activation to the embedded component parts, which explains why compounds such as *teacup* and *honeymoon* and derived words such as *unsauber* and *Sauberkeit* yield priming effects for both L1 and L2 speakers.

For inflected word forms, on the other hand, lexeme-based decomposition only yields a partial analysis of the corresponding letter string, given that forms such as *builds* contain exponents of grammatical feature sets rather than lexemes. Instead, inflected words additionally invoke grammatical processes/rules for mapping exponents to morphosyntactic feature sets. If these rules are fully operative, they ensure complete decomposition of inflected words and, consequently, efficient priming. There are, however, circumstances that may reduce the functionality of these rules. One case is irregular inflection, that is, exceptions that do not support the general rule and in which additional processes (e.g., phonological readjustments) are required to map the exponent to its corresponding morphosyntactic feature set. As mentioned above, reduced priming effects have been reported in such cases relative to inflected forms that fully support the general rule. Another factor that modulates inflectional priming is whether a particular language represents an individual's L1 or L2. As mentioned above, reduced or no priming for regular inflection was found in L2 (unlike in L1) speakers.[5]

These considerations suggest that morphological decomposition during visual word recognition is not just driven by the surface form of complex words (affix stripping), but that morphological processing is also sensitive to the linguistic distinction between word formation (derivation, compounding) on the one hand and inflectional processes on the other, contrary to the view that "no characterization of the inflection versus derivation split has proved relevant" (Marantz, 2016, p. 157). We do, however, concede that more experimental work is needed that directly compares derivation/compounding versus inflection regarding morphological processing to further validate the proposed distinction.

Conclusion

In the current study, we obtained significant masked priming effects for different kinds of derived word forms (prefixed and suffixed, lexically restricted and lexically unrestricted) and different groups of speakers (L1, L2). Furthermore, these priming effects were dissociable from both orthographic and semantic prime–target relatedness, suggesting that they are genuinely morphological in nature. Our findings contrast with previous studies reporting more variability for inflectional priming. We attribute the differences between derivational and inflectional priming to the linguistic contrast between derivation and inflection, which permits direct lexeme-based decomposition for derived words but not for inflected word forms. Although the results from the present study, along with the reviewed results from previous priming experiments, confirm this conjecture, the evidence for a split between derivation/compounding versus inflection with respect to morphological decomposition is still scarce and needs to be ascertained through further studies.

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Notes

1 As explained by Sassenhagen and Alday (2016), performing inferential statistics such as *t* tests to verify the matching of items in different conditions is problematic for the following reasons. First, we would be making inferences about the specific items selected, which a *t* test (or the like) does not allow to make. Second, a nonsignificant result in a *t* test should not be taken as evidence for the absence of a difference.

2 Three of the original 12 prime–target pairs from the semantic set had to be recoded as fillers due to experimental error, leaving 18 prime–target pairs in each list, 9 per prime type in this set. The three removed items are not included in the description of the item characteristics.

3 The tables showing model outputs are meant to present as clearly as possible the results from our main experimental manipulation, namely, priming effects. Therefore, we only included the lines from the model outputs that contain the fixed effect for Prime Type; effects from other predictors, if relevant, are reported in the text.

4 Following the suggestion of one anonymous reviewer, we additionally examined whether Transition Probability (TP) interacts with the morphological priming effects we report. TP is normally defined as the conditional probability of encountering the whole complex word given its stem, and it is computed by dividing the word form frequency of the complex word by the sum of the frequencies of all words sharing the same stem (Hay, 2001; Lehtonen, Monahan, & Poeppel, 2011; Solomyak & Marantz, 2010). For prefixed words, the relevant transition may be from the prefix rather than from the stem; therefore, we also computed TP from prefix by dividing the word form frequency of the prefixed word by its prefix frequency. Because TP is a property of the morphologically related prime, but not of the unrelated prime, we used the same TP for the prefixed and unrelated prime in one analysis testing TP effects on prefixation priming. TP effects on suffixation priming were determined similarly in a separate analysis. Linear mixed-effect models were fitted to log RTs with the fixed effects Group (L1, L2) and Prime Type (prefixed/suffixed, unrelated) and their interaction. The (centered) continuous predictor TP (or TP from prefix, respectively), as interacting with Prime Type, was tested for inclusion. We found that these predictors did not improve model fit, which suggests no effect of TP on the morphological priming effects. However, because our study was not specifically designed to test TP effects, the range of TPs was very limited and substantially varied between prefixed and suffixed words. Hence, whether TP affects prefixation and suffixation priming to different degrees remains a question worth investigating in future research.

5 Two recent large-scale priming studies have identified the source of the L1/L2 difference in inflectional priming (Bosch, Veríssimo, & Clahsen, 2019; Veríssimo, Heyer, Jacob, & Clahsen, 2018), namely, age of acquisition (AoA). The first study, examining a group of 93 Turkish–German bilinguals, revealed that the AoA of the L2 (German) had a pronounced effect on inflectional priming (but not on derivational priming), with nativelike priming if acquisition started before the ages of 5–6 and with gradually declining inflectional priming effects for later ages of acquisition. The second study (Bosch et al., 2019) also showed striking AoA effects on inflectional priming. These findings have been attributed to how and when inflectional rules are learned, specifically to a sensitive period for paradigm-based learning mechanisms during which inflectional rules can be efficiently extracted from the input. A long-term consequence of early acquisition of inflectional paradigms is robust morphological priming from inflected forms. By contrast, later AoAs (i.e., those outside the sensitive period) yield weaker paradigmatic representations and as a result lead to the AoA-related gradual decline in

morphological priming from inflected forms that was found in the above-mentioned studies (for further discussion, see Veríssimo et al., 2018).

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Appendix S1. Experimental Items and Their Characteristics.

Appendix: Accessible Summary (also publicly available at https://oasis-database.org)

How Native and Nonnative Speakers Recognize Complex Words During Reading

What This Research Was About and Why It Is Important

Words that consist of more than one component are defined as morphologically complex. Types of complex words are compound words (*paywall*), derived words (*payer*), and inflected words (*pays*). Previous research has shown that when we understand language, we decompose (break down) complex words into their component parts, which happens, for example, with *paywall* [pay + wall], *payer* [pay + er], and *pays* [pay + s]. However, the efficiency of this process has been shown to vary for different types of morphologically complex words and different speaker groups (native speakers or second language learners). Hence, it is important to understand what causes morphological decomposition to be more or less efficient in language comprehension. The researchers in this study focused on morphological decomposition of derived words in native and nonnative speakers of German. They showed that decomposition of derived words works efficiently for different types of derived words and for speakers who are both native and nonnative.

What the Researchers Did

- The researchers tested 48 native speakers of German and 48 adult learners of German as a second language with relatively advanced proficiency (B2–C2 levels), all residing in Germany at the time of the study.
- The participants saw a series of words (the "target" words) presented one at a time on a computer screen. The participants had to decide if each word was an existing (real) word in German (e.g., *sauber* "clean") by pressing a YES or a NO button. The speed of their responses was recorded.
- Before each target appeared, another word (the "prime") was presented. A prime could either be a derived form of the target word, using a prefix (*unsauber* "not clean") or suffix (*Sauberkeit* "cleanness") or it could be a completely unrelated word (*Kriterium* "criterion"). All derived primes thus contained their target (*Sauberkeit* and *unsauber* contain *sauber*).
- The experiment included different types of derived primes: prefixed words (e.g., *unsauber* "not clean") and suffixed words (e.g., *Sauberkeit* "cleanness") as well as Germanic (e.g., *unhöflich* "rude") or foreign (e.g., *ineffektiv* "ineffective") derived words.

- When language speakers encounter derived primes (such as *Sauberkeit*), they decompose them into their component parts (*Sauber* + *keit*). This leads them to be faster at responding to the target word *sauber*, compared to when it is preceded by the unrelated *Kriterium*, because of the overlap in word parts. To give an English example, when speakers see the prime word *player*, they decompose it into *play* and *–er* and they are then quicker in recognizing a target word *play*, compared to when they had seen an unrelated prime such as *hotel*.

What the Researchers Found

- The researchers found that both native and nonnative speakers of German successfully decomposed derived words. That is, they found both groups recognized the target words faster after seeing related derived words as primes.
- Furthermore, the researchers showed that all types of derived words under investigation (those with prefixes and those with suffixes) were decomposed by both native and nonnative speakers of German.

Things to Consider

- The results for derived words were similar to previous results for compound words (e.g., *paywall*), but differed from previous results for inflected words (e.g., *pays*), for which decomposition has been found to be more variable.
- Speakers—even nonnative speakers, at least at a relatively advanced level of proficiency—appear to be able to fully decompose derived and compound words into their component parts, even though these are not words on their own (e.g., the *–er* in *player* has its own independent function but is not a word).
- However, drawing on findings from other previous studies, it appears that speakers—and especially nonnative speakers—may deal differently with inflected words, like *pays* or *played*. When nonnative speakers' grammar rules are not fully operative (e.g., because they learned the rules later in life), these speakers can be less efficient at recognizing the "inner" structure of such grammatically inflected words.

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