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'*Verstehen*' ('understand') primes '*stehen*' ('stand'): Morphological structure overrides semantic compositionality in the lexical representation of German complex verbs

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A B S T R A C T

The lexical representation of words in Indo European languages is generally assumed to be driven by meaning compositionality. This study examined the lexical representation of complex verbs in German, which is a morphologically rich representative of Indo European languages. Three overt priming experiments manipulated prime target relations between morphological, semantic, and form relatedness. Base verbs (e.g., *binden*, 'bind') were pre ceded by derivations that were semantically related (*zubinden*, 'tie') or semantically unre lated (*entbinden*, 'deliver'), by purely semantically related (*zuschnüren*, 'tie'), form related (*abbilden*, 'depict'), or unrelated (*abholzen*, 'deforest') verbs. To ensure that the procedures were sensitive to semantic and form processing, semantic associates (*Messer Gabel*, 'knife fork') and form controls (*Bordell Bord*, 'brothel board'; *beschreiben reiben*, 'describe rub') were added in Experiment 3. To examine whether lexical representation is affected by modality, prime presentation was further varied between visual (Exp. 1 and 3) and audi tory (Exp. 2).

Semantic facilitation (Exp. 3) and form inhibition (Exp. 2 and 3) were not reliable across experiments, while morphological facilitation was strong and unaffected by semantic relatedness in all three experiments. That is, the priming from semantically opaque deriva tions was equivalent to that from transparent derivations. These findings indicate that the lexical representation of complex verbs refers to the base regardless of meaning compos itionality. Lexical representations in German thus differ from those in other Indo European languages. This new evidence points to the necessity to encompass cross linguistic varia tions in the modeling of lexical representation.

Introduction

Complex words like *departmental* comprise several morphemic constituents, *de*, *part*, *ment*, *al*, that recur in the language in many other words. Since the seventies (Murrell & Morton, 1974; Taft & Forster, 1975), it has been well established that morphemic units affect the recognition of complex words. The much debated question whether complex words are decomposed into constituent units or retrieved as full forms from memory is tightly related with questions regarding the nature of morphological structure and its representation and the locus at which morphological structure operates.

The first question is whether morphological structure differs from that of shared form and meaning. On a distrib uted connectionist account, for instance, morphological structure reflects the learned systematic relationships among word forms and their meanings. Hence, morpholog ical effects emerge from the combined activation of ortho graphic, phonological, and semantic codes (Plaut &

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Gonnerman, 2000; Raveh, 2002; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997). Indeed, morphological effects have been shown to vary according to the gradual overlap of form and meaning between word pairs (Gonnerman, Seidenberg, & Andersen, 2007). Since morphological structure is assumed to emerge as an epiphenomenon of form and meaning overlap, it is not explicitly represented but rather (indirectly) captured by the hidden units in between form codes and semantic codes.

In contrast, localist approaches assume that morphological constituents are explicitly (locally) stored in lexical memory, given that morphological effects have been observed to emerge independently of semantic or form effects (Feldman, 2000; Marslen Wilson, Tyler, Waksler, & Older, 1994; Schreuder & Baayen, 1995; Taft & Forster, 1975). For example, morphological decomposition in English is not affected by orthographic differences between prime and target, such as the missing "e" in *adorable* vs. *adore* (McCormick, Rastle, & Davis, 2009). Priming has also been shown to be independent of phonological overlap (Fowler, Napps, & Feldman, 1985), given that morphologically and phonologically related word pairs (*healer* *heal*) resulted in the same amount of priming as morphologically related word pairs with a phonological change (*health* *heal*).

Similar findings were observed in German (Smolka, Zwitserlood, & Rösler, 2007), where morphologically related words whose stems differ with respect to their surface appearance (*gezogen* *ziehen*, 'pulled pull') primed just as well as morphologically related words with the same orthographic stem (*gekauft* *kaufen*, 'bought buy'). Many localist approaches, though, admit that morphological effects may also be implemented in interactive or connectionist accounts (Smolka, Zwitserlood et al., 2007; Taft, 1994).

Another intriguing question concerns the locus of morphological processes, that is, whether morphological structure operates at the prelexical level that guides lexical access or at the lexical level where meaning is represented. In the work presented here, we specifically consider this latter issue. We will thus briefly review models that assume that morphological processes occur at the prelexical level. Then we discuss in more detail models and findings regarding the lexical level of representation.

Prelexical processing and representation

Early work on prelexical processing often contrasted nonwords of the type *juvenate* and *pertoire* that comprise real stems and pseudostems, respectively (depending on whether the prefixed letter cluster *re* represents a real prefix or a pseudoprefix) and observed that lexical access is gained via morphemic units rather than by whole word units (Taft, 1994; Taft & Forster, 1975; Taft, Hambly, & Kinoshita, 1986). Most recent data that supports prelexical morphological decomposition come from masked priming experiments, where the prime is unavailable for conscious report, so that its effects on the target are assumed to reflect the automatic preactivation of shared representations (for the method of masked priming see Forster, Mohan, & Hector, 2003).

Using the masked priming technique in combination with English or French lexical decision tasks, morphological priming has been obtained with true morphological derivations that were transparently or opaquely related, as in *departure* *depart* and *department* *depart*, respectively. But also pseudoderivations of the *corner* *corn* type, where the prime only appears to bear morphological complexity (*er* occurs as suffix in other English words but is a pseudosuffix in the word *corner*) induced priming. The priming of the latter type has been taken to indicate that any morpheme like ending induces the segmentation process. This segmentation process has been generalized to nonwords as well, as long as they comprise a stem and an affix (e.g., Longtin, Segui, & Hallé, 2003; McCormick et al., 2009; Rastle, Davis, Marslen Wilson, & Tyler, 2000; Rastle, Davis, & New, 2004).

However, priming from pure orthographic similarity without morpheme like endings of the *tinsel* *tin* type (Feldman, 2000; Giraudo & Grainger, 2000; Rastle et al., 2000; Segui & Grainger, 1990), as well as semantic effects (Diependaele, Sandra, & Grainger, 2005; Feldman, O'Connor, & Moscoso del Prado Martín, 2009) heat the debate regarding the exact nature of the segmentation process. Few studies (cf. Diependaele et al., 2005; Feldman, O'Connor, & Moscoso del Prado Martín, 2009) assume morpho semantic segmentation in early visual word recognition, while the majority of studies assume that morphological segmentation operates on a purely orthographic basis, mostly independent of both semantic and true morphological relatedness. According to these models, the segmentation process ceases to affect the word recognition process as soon as the morphemic (or morpheme like) constituents are semantically integrated, thus yielding a recognition process in two stages: in the early prelexical stage complex words are decomposed on an orthographic basis, followed by the second lexical stage or level of representation in which the decomposed constituents are reappraised for semantic and syntactic information (e.g., Meunier & Longtin, 2007; Rastle et al., 2000; Taft & Kougious, 2004; Taft & Nguyen Hoan, 2010).

The so called '*corner* *corn* *effect*' has dominated research in recent years by shifting the focus from lexical processing to prelexical processing in early visual word recognition. One reason may be that the prevailing models predominantly based on English and French findings assume similar lexical representations, as will be discussed below. We now turn to models that explicitly explore the lexical representation of complex words.

Lexical processing and representation

In contrast to masked priming, overt priming taps into lexical processing and representation. The prime is presented either auditorily or visually at long exposure durations (230 ms or 250 ms) and is thus consciously perceived, so that the meaning of the word is retrieved.

Hence, most researchers hold that overt priming triggers morphological decomposition as a high level process, either following whole word access, as assumed by supralexical accounts (Giraudo & Grainger, 2000), or constrained by semantic knowledge. In any case, semantic relatedness between prime and target has been regarded as a precondition for the occurrence of morphological priming. For instance, when prime and target were both morphologically and semantically related, English and French prefixed derivations like *distrust* primed their semantically related stems like *trust*, as well as other prefixed or suffixed derivations like *entrust* or *trustful*. Also, suffixed derivations like *confession* and *confessor* primed each other (under visual visual priming in English, and under cross modal priming in French; see Feldman & Larabee, 2001; Feldman, Soltano, Pastizzo, & Francis, 2004; Meunier & Segui, 2002). However, even though stems like *confess* were primed by semantically transparent derivations like *confessor*, the recognition of stems like *success* was not facilitated by morphologically related but semantically opaque derivations like *successor*. This latter finding was replicated under both cross modal (Longtin et al., 2003; Marslen Wilson et al., 1994) and visual priming with long exposure durations at 230 ms or 250 ms (Feldman et al., 2004; Rastle et al., 2000).

In summary, under experimental conditions in which the prime is consciously perceived, morphological priming has been obtained only if the prime and target are also semantically related.

Interestingly, all accounts based on English, French, or Dutch regardless of whether they hold that morphological decomposition precedes or follows whole word access at the lexical level agree that lexical representation depends on semantic compositionality: Semantically transparent words, whose meaning can be derived from the meaning of their parts, possess a lexical entry that corresponds to their base. A word like *departure* may thus be represented as the base {depart} and the suffix {ure}.[1] In contrast, semantically opaque words like *department*, whose meaning cannot be derived from the meaning of the parts, must be represented in their full form {department}, which in turn may be affixed with other suffixes, such as {al} (Diependaele et al., 2005; Marlsen Wilson, Bozic, & Randall, 2008; Marslen Wilson et al., 1994).

However, this concept of lexical representation contrasts starkly with our previous findings in German (Smolka, Komlósi, & Rösler, 2009): Under overt (unmasked) priming, morphologically related prefixed verbs primed their base to the same extent regardless of whether they were both semantically and morphologically related (of the *aufstehen stehen*, 'stand up stand' type) or only morphologically related (of the *verstehen stehen*, 'understand stand' type). Unlike those of English and French, these findings in German suggest that a complex verb like *understand* is not only decomposed into {under} and {stand} during early visual word recognition but is also lexically represented in this fashion (Smolka et al., 2009). Given that there are hardly any studies of this issue in German, we seek to investigate it more fully. German is an interesting test language to explore lexical representation, since it belongs to the same language family as English and French and thus possesses the concatenative morphology of all Indo European languages, but differs from many of these languages regarding its morphological richness and productivity, as evidenced by the productivity of German complex verbs.

Word pairs that are morphologically related but semantically unrelated are the test case for shared lexical representations, that is, whether the two words share a lexical representation. Such pairs are plentiful among German complex verbs.

German complex verbs

In contrast to pseudoderivations of the *corner corn* type, all German complex verbs even those of the *understand stand* type are real (i.e., etymological) morphological derivations of their base verb. They are very productive and frequently used in standard German and are thus a particularly useful means by which to study the effects of relatedness of meaning to the base verb. For instance, derivations like *hintragen* ('carry to'), *forttragen* ('carry away'), *abtragen* ('carry off'), *auftragen* ('apply'), *vertragen* ('get along'), *ertragen* ('suffer'), alter the meaning relatedness from fully transparent to fully opaque with respect to the base *tragen* ('carry').

Despite some morpho syntactic differences between prefix and particle verbs, they share some semantic properties. That is, whether a particular prefix or particle verb is meaning related with its base, and to what degree, is arbitrary. For example, the prefix *ver* produces the transparent derivation *verschicken* ('mail') of the base *schicken* ('send') as well as the opaque derivation *verführen* ('seduce') of the base *führen* ('guide'); and the particle *an* ('at') produces the transparent derivation *anführen* ('lead'), and the opaque derivation *anschicken* ('get ready').

Psycholinguistic effects of prefix and particle verbs were found to be alike in both German (Drews, Zwitserlood, & Neuwinger, 2000; Smolka et al., 2009) and Dutch (Schriefers, Zwitserlood, & Roelofs, 1991). We therefore do not differentiate between these types in this study and, henceforth, refer to them as 'complex verbs' or 'derived verbs'.

In the following experiments, we sought to explore the lexical representation of such complex verbs. In Experiments 1 and 2, we used a within target design and measured priming from morphologically related and semantically transparent and opaque or purely semantically related complex verbs relative to either unrelated or form related complex verbs. The visual prime presentation at 300 ms SOA in Experiment 1 tested intra modal lexical representation and thus provided a direct comparison to our previous experiments, while cross modal priming in Experiment 2 with auditory primes and visual targets tested modality abstract lexical representation.

Experiment 1

The purpose of the first experiment was twofold: it should replicate the findings reported in Smolka et al. (2009) with an improved design by matching the morpho

[1] In lemma models (cf. Taft & Nguyen-Hoan, 2010) transparent words also have a representation of the whole word that is accessed via the base and suffix.

logical structure of all critical primes, and provide a baseline for the following cross modal experiment.

Using long visual prime exposure durations (of 300 ms SOA), Smolka et al. (2009) tested the effect of semantic transparency on the size of morphological priming relative to an unrelated as well as an identity condition. Morphologically related primes were complex verb derivations that were either transparently or opaquely related to their base verb that served as target. Contrary to the view that semantic meaning presides over conscious word processing, it was found that the magnitude of morphological priming was not modulated by semantic transparency. Instead, morphologically related but semantically opaque verbs (*umkommen*, 'perish') primed their base (*kommen*, 'come') to the same extent as did semantically transparent (*mitkommen*, 'come along') or identity (*kommen*, 'come') primes, while semantically associated verbs (*nahen*, 'approach' *kommen*, 'come') did not induce priming.

The second experiment of Smolka et al. (2009) tested whether the morphological effects could be reduced to the form overlap between complex verbs and their base. However, orthographically similar primes (*kämmen*, 'comb') hindered target recognition (*kommen*, 'come'), whereas, again, semantically opaque derivations facilitated the recognition of the base to the same extent as did transparent derivations. Again, facilitation due to semantic associations was weaker in magnitude than that due to morphological relations.

To tease out semantic effects, the third experiment of Smolka et al. (2009) expanded prime exposure durations to 1000 ms. This time, priming due to semantic associates was significant and as strong as priming due to morphological relatedness. A small semantic transparency effect appeared in the form of accuracy (but not latency) data in favor of semantically transparent over opaque derivations. On the whole, the three experiments displayed strong morphological facilitation that is (a) not modulated by semantic transparency (with the exception of accuracy at extreme prime exposure durations), (b) stronger than semantic facilitation (at SOA 300), and (c) different from form inhibition (that was sometimes nonsignificant).

Even though these results are equivocal with regard to prelexical decomposition, they are hard to explain within the prelexical framework assuming that morphological structure affects only prelexical processing. In particular, morphological effects under long prime exposure durations contradict the notion of a prelexical morphological decomposition mechanism that operates in early visual word recognition and disappears as soon as meaning integration comes into play. Smolka and colleagues interpreted these data as indicating that, in German, pure morphological effects last longer than those usually observed in other Indo European languages, where morphological effects are restricted to early visual word recognition and vanish once participants become aware of the prime, as substantiated under visual priming at long SOAs in English (Feldman et al., 2004; Rastle et al., 2000; Raveh, 2002) and Serbian (Feldman, Barac Cikoja, & Kostić, 2002).

The present study examines how morphological regularities are represented in lexical memory, in particular, whether they are influenced by semantic and form relatedness. Experiment 1 of the present study was closely modeled on the second experiment of Smolka et al. (2009) and was thus conducted with overt visual priming at long prime exposure durations of 300 ms SOA. To avoid word category effects, only verbs were used as materials and many fillers were inserted to prevent expectancy and strategic effects. Most importantly, we again applied a within target manipulation which allowed us to directly compare the effect of each type of prime on the same target. We used simple verbs like *binden* ('bind') as targets, and complex verbs as morphologically related primes. Hence the conditions of semantically transparent (*zubinden*, 'tie') and opaque (*entbinden*, 'deliver') derivations were the same as those used in the original study. Again, we compared priming from semantically transparent derivations with priming from purely semantically related verbs, and measured priming relative to unrelated and form related conditions. Notwithstanding, the design of the present study improved on earlier designs as follows.

First, we matched the morphological structure of all critical primes. In the previous study, unrelated and form controls as well as semantically related verbs were simple verbs. In the present study, all were complex verbs and thus had the same morphological structure (and the same length and number of syllables) as the verbs in the morphologically related conditions: Unrelated controls like *abholzen* ('deforest') were neither morphologically, semantically nor form related with the target, and form related controls like *abbilden* ('depict') possessed a base with the same onset or first syllable as that of the target like *binden* ('bind'), but were otherwise neither morphologically nor semantically related with it. Purely semantically related primes like *zuschnüren* ('tie together') were neither morphologically nor form related with the target.

Second, to provide for a direct comparison between semantically transparent derivations and purely semantically related verbs, we matched these two conditions with respect to their meaning relatedness with the target like *binden* ('bind') and included in both conditions only synonyms of the base, like *zubinden* ('tie') and *zuschnüren* ('tie', 'lace') in the morphological and semantic condition, respectively. Thus we actually compared verbs in two synonym conditions, once with and once without a morphological relation to the base.

Semantic priming has often been tested using pairs such as *cello* and *violin*, which are different in many respects from the base targets used in morphologically relevant conditions like *departure* *depart* or *apartment* *apart* (Marslen Wilson et al., 1994; Rastle et al., 2000). In our previous study (Smolka et al., 2009), we used semantically associated verbs as primes, such as *nahen* *kommen* ('approach come'). Notwithstanding, the semantic synonym condition of the present study improves on the semantic conditions of our earlier work.

Altogether, the primes in all conditions were complex verbs with the same morphological structure and were thus (a) of the same word category, and (b) closely matched on distributional variables like lemma frequency, number of syllables and letters. They differed only with respect to the morphological, semantic, or form relatedness

Table 1
Stimulus characteristics of primes that were semantically transparent derivations (M+S+F+) or semantically opaque derivations (M+S−F+), synonyms (M−S+F−), form relations (M−S−F+) or controls (M−S−F−) of simple verb targets in Experiments 1 and 2.

	Lemma frequency	Word form frequency	Word length	Syllable length	Relatedness score
Target	144.6	34.38	6.88	2.00	–
binden ('bind')	(179.76; 12–799)	(40.56; 0–214)	(1.14; 5–9)	(0; 2–2)	
M+S+F+	6.75	2.13	9.48	3.00	5.60
zubinden ('tie')	(7.07; 0–35)	(2.97; 0–15)	(1.33; 7–12)	(0; 3–3)	(0.52; 4.2–6.6)
M+S−F+	6.65	2.35	9.75	3.08	2.16
entbinden ('deliver')	(8.82; 0–34)	(3.58;0–14)	(1.29; 8–13)	(0.27; 3–4)	(0.53; 1.1–3.1)
M−S+F−	6.55	1.18	9.28	3.03	5.38
zuschnüren ('tie')	(13.08; 0–79)	(1.47; 0–5)	(1.15; 7–12)	(0.16; 3–4)	(0.7; 4.1–6.7)
M−S−F+	5.98/6.70	1.45	9.60	3.03	1.28
abbilden ('depict')	(14.06; 0–70)	(4.07; 0–23)	(1.29; 7–12)	(0.16; 3–4)	(0.42; 1–2.9)
M−S−F−	6.15	1.60	9.08	3.03	–
abholzen ('deforest')	(9.55; 0–47)	(2.9; 0–15)	(1.07; 7–11)	(0.16; 3–4)	

Note: In Experiment 2, some orthographically related primes were replaced with phonologically related ones. Means (*SD* and range in parentheses) are given for the total set of stimuli, sample stimuli are italicized. Frequencies are from the CELEX database (Baayen et al., 1993), count is per million.

with the target. Prime conditions are exemplified in Table 1; all critical items are listed in Appendix A.

We further improved the experimental design to avoid possible episodic memory effects. In contrast to the original study, where a participant saw all prime target combinations, in the present study, each participant saw a target base only once.[2]

In summary, we carried out an overt visual priming experiment to test whether or not complex verbs in German are processed by means of their morphological base. If lexical representation in German is organized according to meaning computability as it is in English (Marlsen Wilson et al., 1994, 2008; Rastle et al., 2000; Rastle et al., 2004; Taft & Nguyen Hoan, 2010), semantically transparent derivations will share a lexical entry with their base, whereas semantically opaque derivations will have their own representation in lexical memory. Accordingly, the former but not the latter will induce priming to their base, and the priming from semantically transparent derivations should be similar to that by morphologically unrelated synonyms. If, however, our assumption holds that lexical representations in German comprise the base (Smolka et al., 2009), we should obtain priming from both semantically transparent and opaque derivations, even though the prime is fully visible.

Method Experiment 1

Participants

Sixty four students of the University of Konstanz were paid for their participation. All were monolingual native speakers of German, were not dyslexic, and reported normal or corrected to normal vision.

Materials

Critical stimuli. Forty base verbs were selected from the CELEX German lexical database (Baayen, Piepenbrock, & van Rijn, 1993). All were monomorphemic, had no prefix, and took only one meaning. The within target design of the present study controls for target frequency, target length, target neighborhood size, and target family size across conditions.

Each base verb was combined with five primes, resulting in 200 prime target pairs (see Appendix A). In contrast to our previous experiments (Smolka et al., 2009), all conditions employed complex verbs, that is, prefix or particle verbs that differed in their relation with the base verb. Derivations of the base were, by definition, morphologically and thus also form related with the target. All other prime conditions were morphologically unrelated with the target. Specifically, prime target relations were defined by three factors: morphological, semantic, and form relatedness with the base verb (e.g., *binden*, 'bind'; see also Table 1): (a) M+S+F+, semantically transparent derivations of the base (e.g., *zubinden*, 'tie'), importantly, were synonyms of the base, like the primes in condition (c) below; (b) M+S F+, semantically opaque derivations of the base (e.g., *entbinden*, 'deliver'); (c) M S+F , morphologically unrelated synonyms of the base verb (e.g., *zuschnüren*, 'tie') were selected by means of the online synonym dictionaries http://www.canoo.net/ and http://www.synonyme.woxikon.de/; (d) M S F+, form related verbs (e.g., *abbilden*, 'depict') were unrelated complex verbs with bases whose onset or first syllable matched that of the target base and differed from the target by a single grapheme (1 or 2 letters); one complex verb was put in the preterit to create form relatedness; and (e) M S F , unrelated verbs (e.g., *abholzen*, 'deforest') were neither morphologically, semantically nor form related.

Table 1 provides all prime characteristics. All morphological derivations (except for a semantically opaque one) were less frequent than their base. Primes across conditions were matched on lemma frequency according to CELEX (Baayen et al., 1993). A one way ANOVA conducted on lemma frequencies indicated that there was no difference between prime conditions, $F < 1$. Primes were further matched on number of letters and syllables. To control for length effects, all but five prefixes or particles consisted of a single syllable. Prefix and particle length ranged from 2 to 5 letters, with a mean length of 2.60 in the M+S+F+ con

[2] Smolka et al. (2009) used repeated-target presentations. Post hoc analyses confirmed that the morphological effects were the same when targets were seen only once.

dition, 2.88 in the M+S F+ condition, 2.58 in the M S+F condition, 2.63 in the form related, and 2.5 in the unre lated condition. Chi Square tests further indicated that prefixes and particles were evenly distributed between all prime conditions, $\chi^2(4) = 8.8$, $p = .068$, and between the two morphologically related conditions in particular, $\chi^2(1) = 3.3$, $p = .517$. The critical set of 200 prime target pairs was selected from a pool of verb pairs that were sub jected to the semantic association test described below.

Semantic association test. A semantic association test was conducted to establish the relatedness between primes and targets for all prime conditions. Sixty six candidate verbs were selected from the CELEX database (Baayen et al., 1993), for each of which two synonyms, two seman tically transparent derivations, two semantically opaque derivations, and two form related verbs were distributed across eight lists, so that each list contained only one prime for the same target verb. The verb intended as the prime preceded the target and both were presented in citation form (stem/ *en*). In total, 528 prime target pairs were tested. One hundred and thirteen participants who did not take part in the experiments proper rated the relation ship between the verbs of each pair on a 7 point scale from *completely unrelated* (1) to *highly related* (7).

The following criteria determined whether or not a base verb and its primes were included in the critical set: The mean ratings for a semantically related pair (M+S+F+ and M S+F) had to be higher than 4, and those for a seman tically unrelated pair (M+S F+ and M S F+) lower than 3. Mean ratings of the final set were 5.6 for semantically transparent derivations (M+S+F+) and 5.4 for synonyms (M S+F), 2.2 for semantically opaque derivations (M+S F+), and 1.3 for form related pairs (M S F+).

A one way ANOVA was performed on mean ratings with items as random variables. The repeated measures factor prime type was highly significant, $F(3,117) = 633.75$, $p < .001$. Scheffé post hoc comparisons indicated that the ratings for semantically transparent der ivations (M+S+F+) and synonyms (M S+F) did not differ from each other, but were significantly higher than those for semantically opaque derivations (M+S F+) or form re lated pairs (M S F+). The difference between the latter two was significant as well.

Fillers. To prevent strategic effects, a total of 264 prime target pairs were added as fillers. All except for twenty four (described below) were unrelated. All had complex verbs as primes, 112 had verbs and 152 had pseudoverbs as targets. Pseudoverbs were constructed by exchanging one or two letters in the stems of real verbs, while preserv ing the phonotactic constraints of German. All pseudoverbs had the same morphological structure as real verbs in that they comprised a pseudostem and the inflectional suffix *en* that represents the infinitive in German. Forty of the pseudoverbs had the same onset as the targets of the crit ical set (e.g., *binden* vs. **binsen*). To ensure that participants did not respond with 'word' decisions for any trial where prime and target had high letter overlap, the same propor tion of form related word nonword pairs as that of the critical set was inserted. To this end twenty four complex verbs were followed by pseudoverbs that held the same onset as the prime's base (e.g., *umwerben* *wersen*) and were thus similar to the *forgery forticle* type used in Mar slen Wilson et al. (1994).

Overall, the large amount of fillers reduced the propor tion of (a) critical prime target pairs to 13%, (b) semanti cally related prime target pairs to 5%, and (c) form related (verb and pseudoverb) pairs to 16% of the whole material set. All filler items differed from those of the crit ical set.

Throughout the experiment, all primes and targets (ex cept for one form related prime, see above) were pre sented in the infinitive (stem/ *en*), which is also the citation form in German.

Apparatus

Stimuli were presented on a 18.1″ monitor connected to an IBM compatible AMD Atlon 1.4 GHz personal computer. Stimulus presentation and data collection were controlled by the *Presentation* software developed by Neurobehavior al Systems (http://www.nbs.neuro bs.com). Response latencies were recorded from the left and right buttons of a push button box.

Procedure

Primes of the same target were rotated over five lists according to a Latin Square design, with one of the five prime target combinations in each list. Participants re ceived only one experimental list and therefore partici pated in all priming conditions (eight items per condition) but saw each target word only once. Each list was divided into four blocks, each block containing the same amount of stimuli per condition. The form related prime pseudoverb pairs and the remaining filler pairs were evenly allocated to the blocks. In total, an experimental session comprised 304 prime target pairs presented in four experimental blocks, with 76 prime target pairs per block. Trial presentation within blocks was pseudo ran domized separately for each participant, so that no more than four consecutive word or nonword targets occurred in a row. Sixteen additional prime target pairs were used as practice trials.

Participants were tested individually, seated at a view ing distance of about 60 cm from the screen. Stimuli were presented in white Sans Serif letters on a black back ground. To make primes and targets physically distinct stimuli, primes were presented in uppercase letters, point 26, 20 points above the center of the screen, targets were presented centrally in lowercase letters, point 30.

Each trial started with a fixation cross in the center of the screen for 200 ms. This was followed by the presenta tion of the prime for 200 ms, followed by an offset (=blank screen) for 100 ms, resulting in a stimulus onset asyn chrony (SOA) of 300 ms. After the offset, the target imme diately followed and remained on the screen until a participant's response. The intertrial interval was 1500 ms. Participants were instructed that they will see a fixation cross, a first word, and a second word to which they should make a lexical decision as fast and as accu rately as possible. 'Word' responses were given with the in dex finger of the dominant hand, 'pseudoword' responses with the subordinate hand. Feedback was given on both correct (*'richtig'*) and incorrect (*'falsch'*) responses during the practice session, and on incorrect responses during the experimental session.

The experiment lasted for about 30 min. Participants self administered the breaks between blocks, and took at least one longer break.

Results Experiment 1

Three participants whose error rates (>16%) exceeded three standard deviations of the overall error mean (5.6%) were removed, so that the data of 61 participants were in cluded in the analyses. Means over word and nonword re sponses were calculated separately for each participant. Response times (RTs) above 2000 ms or 3 standard devia tions from a participant's mean were excluded (1.5% of the critical data). Mean response latencies were calculated for correct responses; mean error rate was 1.4% for the crit ical trials. Uncorrelated RT and error means of the experi mental conditions indicated that there was no speed accuracy trade off, $r(3) = .83075$, $p = .081$. RT and error means are provided in Table 2.

A repeated measures logistic regression was run on accuracy data with prime type as main effect and partici pants as random intercept. Given that response accuracy did not reveal any significant effects (overall effect of prime type, $F(4,2371) = 0.25$, $p = .91$, in the following only effects with response latency will be reported.

For response latencies, a one way ANOVA with repeated measures factor prime type (M+S+F+/M+S F+/M S+F / M S F+/M S F) was performed with participants (F_1) and items (F_2) as random variables. The effect of prime type was highly significant, $F_1(4,240) = 6.72$, $p < .001$, $F_2(4,156) = 5.36$, $p < .001$. A set of planned comparisons was performed to establish the amount of priming relative to the unrelated condition. These priming effects are de picted in the left panel of Fig. 1. Morphologically related primes significantly facilitated responses relative to the

Table 2
Mean response latencies and accuracies in Experiment 1 (Visual SOA 300).

Prime type	RT (*SD*)	Effect	Error (*SD*)
M+S+F+ *zubinden* ('tie')	563 (88)	28**	1.0 (3.5)
M+S–F+ *entbinden* ('deliver')	566 (84)	25**	1.4 (4.0)
M–S+F– *zuschnüren* ('tie')	580 (102)	(10)	1.4 (5.6)
M–S–F+ *abbilden* ('depict')	600 (100)	(–9)	1.6 (4.8)
M–S–F– *abholzen* ('deforest')	591 (97)		1.6 (4.8)

Note: Mean RTs in milliseconds (*SD* in parentheses) and mean percentage of errors (*SD*) for verb targets like *binden* ('bind') preceded by a visually presented semantically transparent derivation (M+S+F+), a semantically opaque derivation (M+S–F+), a synonym (M–S+F–), a form-related verb (M–S–F+), or by an unrelated control (M–S–F–). Priming effects are calculated relative to the unrelated condition. Nonsignificant effects are given in parentheses.

** $p < .01$ indicates significance levels for analyses by both participants and items.

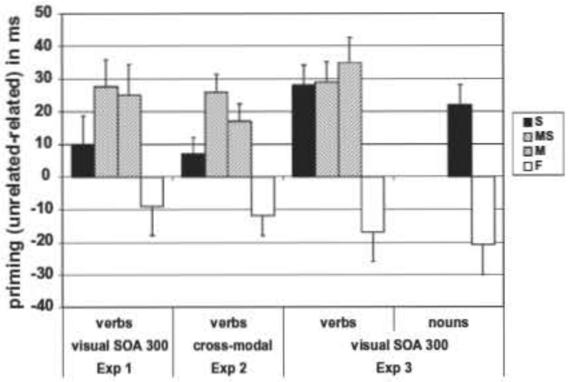

Fig. 1. Priming effects (unrelated minus related) induced by form-related (F), purely semantically related (S), morphologically and semantically related (MS), or purely morphologically related (M) prime–target pairs in Experiment 1 (visual SOA 300), Experiment 2 (cross-modal), and Experiment 3 (visual SOA 300) in the mid, left, and right panel, respectively. Experiment 3 further differentiates between conditions in which verbs or nouns were used. The *y*-bars provide the standard errors of the means.

unrelated condition. This was true for both semantically transparent (M+S+F+), $F_1(1,240) = 10.33$, $p < .005$, $F_2(1,156) = 8.46$, $p < .005$, and opaque derivations (M+S F+), $F_1(1,240) = 8.26$, $p < .005$, $F_2(1,156) = 7.19$, $p < .01$. Most importantly, the contrast between the two conditions, namely that between 28 ms and 25 ms, was not significant (F_1 and $F_2 < 1$), indicating that morphologi cal priming was unaffected by the semantic relation be tween prime and target.

By contrast, neither synonyms (M S+F), $F_1(1,240) = 1.45$, $p = .230$, $F_2(1,156) = 2.05$, $p = .155$, nor form related primes (M S F+), $F_1(1,240) = 1.15$, $p = .286$, $F_2 < 1$, significantly differed from the unrelated condition, even though they showed numerically faster and slower responses, respectively.

The contrast between the two semantically related prime target pairs synonyms and semantically transpar ent derivations was significant in the analysis by partici pants, $F_1(1,240) = 4.04$, $p < .05$, though not by items, $F_2(1,156) = 2.18$, $p = .142$, and indicated that morphologi cally related primes more strongly facilitated responses than did semantically related primes. All above contrasts were further confirmed by more conservative post hoc comparisons (Student Newman Keuls) run on the analy ses by participants and items.

Discussion

In Experiment 1, we examined whether the factors mor phological, semantic, and form relatedness affect target recognition under visual prime presentations with long exposure durations. The results showed that lexical deci sion latencies were facilitated by morphological related ness, but not by the pure meaning or form relatedness between prime and target. Most importantly, morphologi cal facilitation was not affected by semantic transparency. In this respect, we replicated our previous findings (Exp. 1 and 2 in Smolka et al., 2009) under the same prime condi tions, but in different labs, with different materials, im proved design and controls. We thus believe that we have robust evidence for morphological priming of German verbs.

In contrast to morphological priming, semantic priming was not significant. This is of particular interest, since both purely semantically related primes and semantically trans parent derivations were synonyms of the base verbs and thus shared the same semantic relatedness to the base verbs.

Non significant facilitation by semantically associated (but morphologically unrelated) verbs has already been re ported in previous behavioral experiments (cf. Smolka et al., 2009; Zwitserlood, Drews, Bolwiender, & Neuwinger, 1996).[3] Since it is not clear why German verbs show unsta ble semantic facilitation effects, we will deal with this issue specifically in Experiment 3. Be that as it may, the fact that priming in the morphological condition was numerically double the size of the priming in the semantic synonym condition provides strong evidence that morphological priming is robust and independent of meaning relatedness.

Form inhibition did not reach significance. Neverthe less, response latencies were numerically slowed which concurs with previous findings that the orthographic sim ilarity of a clearly visible prime (at long SOAs of 230 ms or more) hinders target recognition in English (Feldman, 2000; Pastizzo & Feldman, 2002; Rastle et al., 2000), Dutch (Drews & Zwitserlood, 1995; Segui & Grainger, 1990), Ger man (Drews & Zwitserlood, 1995; Smolka et al., 2009), and French (Grainger, 1990; Segui & Grainger, 1990). In sum mary, we may conclude that complex verbs in German show strong morphological effects that are independent of semantic and form relatedness.

According to models of visual word recognition, this provides evidence for shared lexical representations be tween morphological derivations and their base, even in the case of semantically opaque derivations. That is, we may assume that both the semantically transparent deri vation *aufstehen* ('stand up') and the semantically opaque derivation *verstehen* ('understand') are lexically repre sented as {stehen} and the prefixes {auf} and {ver}, respectively.

Experiment 2

In Experiment 1, we presented visual primes at long exposure durations of 300 ms and obtained morphological effects without any difference between semantically trans parent and opaque derivations. However, given that primes and targets were presented within the same modality, it is possible that these effects are restricted to modality specific representations and do not extend to ab stract representations.

[3] In contrast to the behavioral experiments, EEG-experiments with semantically associated verbs revealed significant facilitation in form of N400 effects (i.e. more negative going amplitudes for unrelated than for associated verbs; cf. Smolka, Gondan, & Rösler, 2008; Smolka, Khader, Wiese, Zwitserlood, & Rösler, 2013). Further, morphologically related (transparent and opaque) verbs induced larger N400 effects than purely semantically related verbs.

Abstract lexical representations are assumed to be traced under overt cross modal priming conditions (Mar slen Wilson et al., 1994), where an auditory (and thus con sciously perceived) prime precedes a visually presented target, or where an overt visual prime precedes an auditory target. Shared lexical representations thus need to be modality independent. Using the fragment completion task, Rueckl and Galantucci (2005) showed that long term morphological effects include a modality specific compo nent that occurs before modality independent effects. The aim of Experiment 2 was to examine whether the mor phological effects obtained in Experiment 1 are confined to modality specific processes or whether they extend to modality independent processes as well.

Studies in several Indo European languages, so far, have failed to establish modality independent lexical represen tations for pure morphological effects. Data gathered from cross modal priming in English (Marslen Wilson et al., 1994) and French (Longtin et al., 2003) rather support the notion that semantic relatedness and compositionality are a prerequisite for shared abstract lexical representa tions. Under cross modal (auditory visual) priming, suf fixed derivations like *glaciaire* and *glaçon* primed each other in French (Meunier & Segui, 2002), though not in English (Feldman & Larabee, 2001; Feldman et al., 2004; Marslen Wilson et al., 1994). Both English and French pre fixed derivations like *distrust*, which are most similar to those of the present study, primed semantically related stems like *trust*, as well as other prefixed or suffixed deri vations like *entrust* or *trustful* (Feldman & Larabee, 2001; Marslen Wilson et al., 1994; Meunier & Segui, 2002). As a general rule, whenever derivations were semantically transparent they produced priming to their base, but not when they were semantically opaque: *Confessor* primed *confess* but *successor* did not prime *success* (Marslen Wil son et al., 1994).

Using cross modal priming, only studies in Arabic ob tained strong morphological priming without effects of semantic compositionality (Boudelaa & Marslen Wilson, 2004a, 2004b). Interestingly, in Hebrew, another Semitic language, morphological priming was strongly influenced by semantic transparency (Frost, Deutsch, Gilboa, Tannen baum, & Marslen Wilson, 2000), even though morphologi cal priming was repeatedly found to be independent of semantic and form effects in early visual word recognition (i.e., under masked priming conditions, see e.g., Frost, Kug ler, Deutsch, & Forster, 2005).

Generalizing across language families, research on mor phological processing, so far, has recognized that lexical organization is guided by morphological structure in Semitic languages and by semantic compositionality in Indo European languages. However, Experiment 1 of the present study as well as previous experiments (Drews et al., 2000; Smolka et al., 2009) provided evidence that lexical representation not only in Arabic but also in German is guided by morphological structure. To explore whether morphological structure of German complex verbs is represented via modality specific or modality independent representations, we carried out a cross modal priming experiment with auditory primes preceding visu ally presented targets.

Several studies have shown processing asymmetries that support the assumption of both modality specific and modality independent subprocesses for lexical representation (e.g., Feldman & Larabee, 2001; Grainger & Ferrand, 1994). For example, in the framework of a bi modal interactive activation model, Grainger and Ferrand (1994) suggested parallel routes for visual and auditory word recognition that are heavily interconnected both at the prelexical and lexical level.

Sublexical, lexical, and supralexical accounts predict that under overt cross modal priming conditions morphological priming should surface only if primes and targets share a semantic relationship, albeit on different grounds. In the sublexical account, the morphological structure of a word is relevant for the blind parsing routine at the prelexical level, but is not relevant when meaning integration comes into play under overt priming conditions. Hence, even though semantically opaque derivations share the same prelexical decomposition units, they should not prime their base, since they do not share the same lexical representation.

In the supralexical account, morphological structure is retrieved through a lexical representation. Hence, (cross modal) morphological priming should only be obtained with primes and targets that have a semantically transparent relationship, since only these will share representations at the morpheme level (Diependaele et al., 2005).

But if complex verbs in German share not only modality specific but also abstract lexical representations of the base, we should obtain priming from semantically opaque derivations. Experiment 2 was conducted to test this issue.

Method Experiment 2

Participants

Ninety three students at the University of Konstanz, who did not take part in Experiment 1, were paid for their participation. All were native speakers of German and reported normal or corrected to normal vision, and no hearing impairment.

Materials

All verb stimuli and prime conditions of Experiment 1 were used except for some form related primes (M S F+). Seven orthographically but not phonologically related primes were exchanged for complex verbs whose base had the same onset (and the same vowel quality) as the target, but a different phoneme in the rhyme (for exchanged items see Appendix A). Allocation of experimental items (with the exchanged form related primes) to five lists was the same as in Experiment 1; each participant saw one list, with all conditions and eight items per condition.

Apparatus

Recording of auditory stimuli. A female (native speaker of German) speech therapist was recorded for the primes. Recording took place in a sound attenuated cabin by means of a digital audio recorder (Tascam HD P2; sampling rate 44.1 kHz, 16 Bit, mono). To avoid intonation effects, each word was recorded twice in randomized order. Words were segmented and normalized at 95% of the maximal amplitude. The duration of the auditory primes was, on average, 933 ms for form related primes (M S F+), 940 ms for synonyms (M S+F), 966 ms for unrelated primes (M S F), 974 ms for semantically transparent derivations (M+S+F+), and 982 ms for semantically opaque derivations (M+S F+). A one way ANOVA with between items factor prime type indicated that prime duration did not differ across conditions, $F_2(4,195) = 1.88$, $p = .116$.

Visual stimuli were presented on a 19″ monitor IPS panel connected to an IBM compatible Dual Core 2 personal computer. Auditory primes were presented via headphones *Sennheiser* (HD25II 70Ω). Stimulus presentation and data collection were controlled by the *Presentation* software developed by Neurobehavioral Systems (http://www.nbs.neuro bs.com). Response latencies were recorded from the left and right buttons of a push button box.

Procedure

Besides the stimulus presentation, the procedure was the same as in Experiment 1. Each trial started with a fixation cross in the center of the screen. After 1000 ms, the auditory prime was presented via headphones. The fixation cross remained on the screen until 100 ms before the end of the auditory prime, followed by an offset (blank screen) for 100 ms. The target appeared immediately at the offset of the auditory prime in the center of the screen (in lower case, white Sans Serif letters, point 30, on a black background), and remained on the screen until a participant made a lexical decision ('word' responses were made with the dominant, 'pseudoword' responses with the subordinate hand). The intertrial interval was 1500 ms.

Results Experiment 2

The same outlier procedure was used as in Experiment 1. Three participants whose error rates (>16%) exceeded three standard deviations of the overall error mean (5.3%) were removed, so that the data of 90 participants were included in the analyses. Means over word and nonword responses were calculated separately for each participant. Reaction times (RTs) exceeding 2000 ms or 3 standard deviations from a participant's mean were excluded (1.9% of the critical data). Mean response latencies were calculated for correct responses; mean error rate was 0.97% for the critical trials. Positively correlated RT and error means of the experimental conditions indicated that there was no speed accuracy trade off, $r(3) = .92785$, $p < .05$. RT and error means are provided in Table 3.

A repeated measures logistic regression was run on accuracy data with prime type as main effect and participants as random intercept. Since response accuracy did not reveal any significant effects (overall effect of prime type, $F(4,3505) = 1.29$, $p = .270$, in the following only effects with response latency will be reported.

For response latencies, a one way ANOVA with repeated measures factor prime type (M+S+F+/M+S F+/M S+F /M S F+/M S F) was performed with participants (F_1) and items (F_2) as random variables. Again, the effect of

Table 3
Mean response latencies and accuracies in Experiment 2 (cross-modal).

Prime type	RT (*SD*)	Effect	Error (*SD*)
M+S+F+ *zubinden* ('tie')	573 (77)	26***	0.6 (3.2)
M+S−F+ *entbinden* ('deliver')	582 (75)	17*	0.8 (3.2)
M−S+F− *zuschnüren* ('tie')	592 (71)	(7)	0.8 (3.7)
M−S−F+ *abbilden* ('depict')	611 (77)	−12*	1.7 (4.7)
M−S−F− *abholzen* ('deforest')	599 (76)		1.0 (3.4)

Note: Mean RTs in milliseconds (*SD* in parentheses) and mean percentage of errors (*SD*) for verb targets like *binden* ('bind') preceded by an auditorily presented semantically transparent derivation (M+S+F+), a semantically opaque derivation (M+S−F+), a synonym (M−S+F−), a form-related verb (M−S−F+), or by an unrelated control (M−S−F−). Priming effects are calculated relative to the unrelated condition. Nonsignificant effects are given in parentheses.
* $p < .05$ indicates significance levels for analyses by both participants and items.
*** $p < .001$ indicates significance levels for analyses by both participants and items.

prime type was highly significant, $F_1(4,356) = 13.00$, $p < .001$, $F_2(4,156) = 10.44$, $p < .001$. Planned comparisons were performed to establish effects relative to the unrelated condition. Priming effects are depicted in the mid panel of Fig. 1. As in Experiment 1, morphological priming was significant, by both semantically transparent (M+S+F+), $F_1(1,356) = 20.34$, $p < .001$, $F_2(1,156) = 14.15$, $p < .001$, and opaque derivations (M+S F+), $F_1(1,356) = 8.55$, $p < .005$, $F_2(1,156) = 6.09$, $p < .05$. Again, the difference between semantically transparent and opaque derivations was not significant, $F_1(1,356) = 2.52$, $p = .114$, $F_2(1,156) = 1.68$, $p = .198$, indicating that morphological priming was unaffected by the semantic relatedness between prime and target.

As in Experiment 1, synonyms (M S+F), even though they slightly speeded responses, did not induce significant facilitation, $F_1(1,356) = 1.66$, $p = .198$, $F_2(1,156) = 1.02$, $p = .314$. In contrast, form related primes significantly inhibited responses, $F_1(1,356) = 4.30$, $p < .05$, $F_2(1,156) = 4.74$, $p < .05$.

Finally, the contrast between synonym primes and semantically transparent derivations was also significant, $F_1(1,356) = 10.38$, $p < .005$, $F_2(1,156) = 7.57$, $p < .01$, and indicated that morphological relatedness was greater than semantic relatedness. All above contrasts were further confirmed by more conservative post hoc comparisons (Student Newman Keuls) run on the analyses by participants and items.

Discussion

Experiment 2 examined whether German complex verbs share a modality abstract lexical representation with their base or whether abstract representations are determined by semantic compositionality, as is the case in other Indo European languages (Marslen Wilson et al., 1994).

Most importantly, and in contrast to the predictions of previous cross modal priming studies in Indo European languages (Longtin et al., 2003; Marslen Wilson et al., 1994), we obtained morphological priming effects for both types of derivations, semantically transparent as well as opaque. That is, not only *zubinden* ('tie') but also *entbinden* ('deliver') produced priming to their base *binden* ('bind'). The cross modal testing conditions further provide evidence that modality independent representations possess morphological structure. This is at odds with models assuming that semantic relatedness and compositionality are a prerequisite for shared lexical representations (Diependaele et al., 2005; Marlsen Wilson et al., 2008; Rastle et al., 2000).

Significant form inhibition confirmed that the morphological effects cannot be attributed to mere form overlap between morphologically related primes and targets. Form inhibition under cross modal priming conditions further fits with previous findings that phonological similarity hinders target recognition (Pastizzo & Feldman, 2002), though phonological relatedness did not necessarily induce significant inhibition in several previous cross modal experiments (cf. Frost et al., 2000; Experiments 1, 2, and 5 in Marslen Wilson et al., 1994; Pastizzo & Feldman, 2002).

In contrast to the significant morphological and form effects, pure synonym priming was not significant and thus replicates the nonsignificant semantic effect in Experiment 1. Interestingly, the priming patterns of the two semantically related conditions (transparent derivations and synonyms) in Experiment 2 closely resembled those of the first experiment in spite of the modality difference across experiments. Given that both types of prime semantically transparent derivations and purely semantically related primes were all synonyms of the base, the facilitation by the former in contrast to the lack thereof by the latter stresses the effect of morphological relatedness even more. Since this lack of semantic facilitation contrasts with previous cross modal priming studies that did observe priming from synonyms (cf. Exp. 2 in Marslen Wilson et al., 1994), we deal with this issue in the following experiment.

Thus, the evidence of form inhibition combined with the lack of semantic facilitation clearly demonstrates that the strong morphological facilitation effects were not due to a combination of form and meaning overlap, as is suggested by connectionist approaches (Plaut & Gonnerman, 2000). So far, strong morphological effects without effects of semantic compositionality are thus only evidenced in German and Arabic (Boudelaa & Marslen Wilson, 2004a, 2004b).

Experiment 3

Experiments 1 2 yielded strong morphological effects, independent of semantic transparency, while neither semantic nor form effects were reliably significant. Nevertheless, the results raise the following questions: First, were the procedures sensitive to detecting semantic influences? If we never observed semantic priming, questions would arise about the procedure used to detect semantic influences. In contrast to studies in English or French, the semantic effects were not significant under either visual priming at long SOAs or cross modal priming. Under such priming conditions, studies in these languages compared morphological with semantic priming by using mostly noun pairs that were either semantic associates or synonyms, such as *cello violin*. Even if verbs occurred, many of these, particularly in English, may also be interpreted as nouns, like *circle* and *ring* or *gamble* and *risk* (e.g., Marslen Wilson et al., 1994; Rastle et al., 2000). Since we applied a within target design in Experiments 1 2, we used semantically related verbs both simple and complex ones (in Smolka et al., 2009 and Experiments 1 2, respectively). Given that there are no other studies that have tested the semantic facilitation between verbs, we have suggested that the unstable semantic facilitation may be a characteristic of verbs in general or of German verbs in particular. To test this assumption and to make sure our procedure is sensitive to detecting semantic influences, we added semantically related noun pairs that are expected to show priming, such as *cat mouse*, *teacher student*, to the semantically related verb pairs in Experiment 3 (see Appendix B).

If it is semantic rather than morphological priming that distinguishes German from other languages, we should find no semantic but strong morphological effects. If, however, our previous semantic priming effects were unstable because of a word category effect (i.e., because we used verbs only), we should find strong semantic priming from noun pairs alongside morphological priming on the verbs. Moreover, if there is again no difference between priming from transparent and opaque complex verbs, even under conditions when semantic information does influence performance, this will verify that the observed morphological effects in German are real.

Second, were the procedures sensitive to detecting form influences? Because of the within target manipulation, we used form controls that introduced a change in the rime, such as *verlauten laufen*, and not form controls where targets are fully embedded orthographically and phonologically at the end of the prime, such as *replay lay* in English. This difference is potentially critical because in the morphological conditions, the targets are fully embedded at the end of the prime. The question thus remains whether the statistical difference with the morphological conditions will still hold if form controls are tested that respect the word ending. We thus introduced two form conditions in which targets were completely orthographically embedded in the prime. To this end, we used form controls of the *replay lay* type with prefixed verbs as primes, as were previously used in Dutch (e.g., Diependaele, Sandra, & Grainger, 2009). To make this condition as similar as possible to those in Experiments 1 and 2 of the present study, it was comprised entirely of verbs. We selected complex verbs as primes that completely contained the target base verb at the end, as in *bewerben erben* ('apply inherit'). We further used form controls of the *brothel broth* type, as previously used in several studies in English (e.g., Rastle et al., 2000, 2004). For this purpose, we used mixed word classes, mostly nouns and adjective pairs that possessed the same beginning, as in *Bordell Bord* ('brothel board'). This design further allowed us to differentiate between form effects of verbs and nouns, respectively.

If the difference between morphological and form effects disappears, that is, if *replay lay* like items produce the same amount of facilitation as *understand stand* like items, this would shed an entirely different light on the interpretation of our previous results. By contrast, a difference between effects of pure morphological relatedness (*understand stand*) and pure form relatedness (*replay lay*) would provide strong evidence that the morphological effects are independent of form overlap.

Third, were the procedures sensitive to verbs only? Given that word category is known to affect lexical processing (e.g., Vigliocco, Vinson, Arciuli, & Barber, 2008), we confined ourselves strictly to verbs in our previous experiments (Exp. 1 and 2 of this study, Exp. 1 3 in Smolka et al., 2009). It is possible, though, that the morphological effects were generated in a verb only environment. In order to demonstrate that the morphological effects generalize under conditions that employ mixed word categories, Experiment 3 used half nouns and half verbs. To this end, and in contrast to our previous experiments where we used verbs only and within target manipulations, the new semantic and form conditions required an across target manipulation. In fact, Experiment 3 provides a similar design as the ones used in previous studies in other languages (e.g., Marslen Wilson et al., 1994; Meunier & Segui, 2002; Rastle et al., 2000). To compare Experiment 3 with our previous experiments that were mostly conducted with visual primes, Experiment 3 was also tested under visual priming at 300 ms SOA.

To summarize, Experiment 3 was conducted to examine whether the morphological effects will survive under conditions that promote semantic and form priming across mixed word classes. If our previous morphological effects emerged due to any procedural issues, we expect priming from semantically transparent derivations only. But if lexical representation in German constitutes the base irrespective of semantic or form effects, we should obtain priming from both semantically transparent and opaque derivations and no effect of semantic transparency.

Method Experiment 3

Participants

Fifty seven students of the University of Konstanz who had not participated in any of the previous experiments were paid for their participation. All were monolingual native speakers of German, were not dyslexic, and reported normal or corrected to normal vision.

Materials

Critical stimuli. As in Experiments 1 2, prime target relations were defined by three factors: morphological, semantic, and form relatedness with the target. One hundred and twenty prime target pairs were selected, 20 pairs in each of six conditions (see also Table 4), with two conditions representing each of the three factors morphological, semantic, or form relatedness.

Items in the conditions representing the morphological factor (M+S±F+) were drawn from those used in Experiments 1 2. They comprised complex verbs as primes that were morphological derivations of the base and were

Table 4
Prime characteristics in Experiment 3: semantically transparent derivations (M+S+F+), semantically opaque derivations (M+S−F+), semantic synonyms or associates (M−S+F−), form controls (M−S−F+), and their matched unrelated controls.

Prime	Target	Lemma frequency	Word form frequency	Word length	Syllable length	Relatedness score
Morphological relatedness						
M+S+F+ verbs	*lesen* ('read')	7.15	2.3	9.80	3.00	5.60
vorlesen ('read to so.')		(8.07; 0–35)	(3.37; 0–15)	(1.15; 8–12)	(0; 3–3)	(0.41; 4.8–6.3)
Unrelated		7.95	2.60	9.47	3.05	–
		(8.79; 0–38)	(3.84; 0–16)	(1.19; 8–12)	(0.22; 3–4)	
M+S−F+ verbs	*führen* ('guide')	6.45	2.35	9.55	3.10	1.85
verführen ('seduce')		(8.26; 0–33)	(3.62; 0–14)	(1.36; 8–12)	(0.31; 3–4)	(0.44; 1.1–2.7)
Unrelated		7.70	3.1	9.25	3.10	–
		(9.64; 0–35)	(4.58; 0–16)	(1.12; 8–12)	(0.31; 3–4)	
Semantic relatedness						
M−S+F− verbs	*fordern* ('demand')	31.15	10.25	9.60	3.30	5.53
verlangen ('require')		(48.06; 0–174)	(16.07; 0–54)	(1.23; 7–12)	(0.47; 3–4)	(0.82; 3.8–6.7)
Unrelated		33.75	13.6	9.58	3.40	–
		(52.1; 0–190)	(22.2; 0–81)	(1.23; 7–12)	(0.5; 3–4)	
M−S+F− nouns	*Gabel* ('fork')	35.45	26.05	5.30	1.65	–
Messer ('knife')		(40.51; 2–117)	(34.16; 1–93)	(1.59; 2–9)	(0.49; 1–2)	
Unrelated		39.35	34.35	5.15	1.70	–
		(40.89; 3–118)	(38.79; 2–114)	(1.23; 3–9)	(0.47; 1–2)	
Form relatedness						
M−S−F+ verbs	*leiden* ('suffer')	8.00	3.05	9.25	3.10	–
bekleiden		(12.51; 0–50)	(5.19; 0–18)	(1.29; 7–11)	(0.31; 3–4)	
('dress')		9.05	3.9	9.05	3.10	–
Unrelated		(14.21; 0–59)	(7.28; 0–30)	(1.32; 7–11)	(0.31; 3–4)	
M−S−F+ nouns	*Bord* ('board')	96.21	85.11	6.35	2.20	–
Bordell		(214.1; 0–870)	(214.2; 0–867)	(1.31; 4–10)	(0.62; 1–4)	
('brothel')		93.20	42.15	6.30	2.20	–
Unrelated		(251.66; 0–1138)	(82.78; 0–336)	(1.26; 4–10)	(0.62; 1–4)	

Note: Means (*SD* and range in parentheses) are given for the total set of stimuli, sample stimuli are italicized. Frequencies are from the CELEX database (Baayen et al., 1993), count is per million.

either (a) M+S+F+, semantically transparent (e.g., *vorlesen lesen*, 'read to so. read') or (b) M+S F+, semantically opaque (e.g., *verführen führen*, 'seduce guide'). As in the previous experiments, semantically transparent derivations were synonyms of the base.

Of the two conditions representing the semantic factor (M S+F) one condition employed verbs only, the other nouns only. As in Experiments 1 2, (c) the verb primes were complex verbs that were synonyms of the base verb, but morphologically and orthographically unrelated to it (e.g., *unterstützen helfen,* 'support help', *verlangen fordern*, 'require demand'). Synonyms were defined as in Experiments 1 2 and selected from the database provided in Smolka and Eulitz (submitted for publication). The meaning relatedness of these synonyms to the base verbs should be, on the one hand, as strong as that by morphologically related and semantically transparent verbs, and on the other hand, stronger than that by morphologically related but semantically opaque verbs. To this end, we conducted a one way ANOVA on association ratings for these three verb types. The highly significant effect, $F(2,56) = 272.15$, $p < .001$, and Scheffé post hoc comparisons indicated that both types of semantically related verbs, morphologically related (5.64) and morphologically unrelated ones (5.53) were rated as being highly meaning related with the base (and with no difference between the two) in contrast to the morphologically related but semantically opaque verbs (1.85).

The semantic noun set (d) included morphologically and orthographically unrelated, but semantically associated nouns like *Biene Honig* ('bee honey') and *Onkel Tante* ('uncle aunt'). These prime target pairs were selected from an association task conducted with 11 students (who did not participate in the experiment proper). Participants were presented 32 common nouns and asked to name the first association that came to their mind. For example, 11/11 students named the word *Tante* upon hearing *Onkel*, so that *Tante* was used as target to the prime *Onkel*.

Also with regard to the two conditions representing the form factor (M S F+), one comprised verbs only and was of the *replay lay* type while the other comprised mostly nouns and was of the *brothel broth* type: (e) in the form related verb condition, all primes were complex verbs that comprised the whole target base verb at the end, but were morphologically and semantically unrelated to it (e.g., *bekleiden leiden*, 'dress suffer'); (f) in the second form condition, primes comprised the whole target word at the beginning, but were morphologically and semantically unrelated to it (e.g., *Bordell Bord*, 'brothel board'). All primes and targets were morphologically simple and mostly consisted of nouns (as well as some adjectives, adverbs, and verbs). For reasons of simplicity, we refer to this condition as the form related noun condition (in contrast to the form related verb condition).

For each of the 120 related primes, we pair wise selected an unrelated control (or baseline) word that (a) was morphologically, semantically, and orthographically unrelated to the target and (b) matched to the related prime on word class, morphological complexity, number of letters and syllables. In addition, unrelated primes were pair wise matched to related primes on lemma frequency according to CELEX (Baayen et al., 1993). A two way ANOVA with factor prime type (Morphological transparent/ Morphological opaque/Semantic verbs/Semantic nouns/ Form verbs/Form nouns) and relatedness (related/unrelated) was conducted on lemma frequencies. The effect of prime type was significant, $F(5,227) = 4.64$, $p < .001$, and post hoc comparisons (Student Newman Keuls) indicated that the lemma frequencies of the form related nouns were higher than those in the other conditions, which in turn did not significantly differ from each other. Most importantly, neither the effect of relatedness nor the interaction was significant. Further one way ANOVAs separately for each prime type indicated that there was no difference between related and matched unrelated primes in any of the conditions, all $F < 1$. Average values for each of these variables across the six conditions are shown in Table 4. All stimuli are listed in Appendix B.

Related fillers. To prevent strategic effects, 60 related word nonword pairs were constructed to ensure that participants did not respond with 'word' decisions for any trial where prime and target were orthographically or semantically similar. To this end, the same proportion of form related and meaning related word nonword pairs as that of the critical set was constructed. First, to mimic the morphological conditions (a) and (b), twenty complex verbs were followed by pseudoverbs that changed the primes' base by a single letter in the rime, as in *umrechnen recknen*. Second, similar to the semantic conditions (c) and (d), 10 complex verbs and 10 nouns were paired with semantic verb or noun associations that were changed into pseudowords by exchanging a single letter in the rime, as in *abbürsten säupern* ('brush cleam') or *Sonne Monf* ('sun moof'), respectively. Third, similar to the form conditions (e) and (f), 10 complex verbs and 10 nouns embedded the whole nonword target, as in *abkaufen aufen* or *Trompete Trompe*, respectively. Nonword pairs of the type (e) and (f) were thus similar to the ones used in Marslen Wilson et al. (1994) in which the target was fully contained within the prime, as in *donkey donk* or *bishop bish*. Related prime nonword pairs are listed in Appendix B. To match the critical related and unrelated stimuli in a list, 60 unrelated prime nonword pairs of the types (a) (f) were created, 10 of each type.

Unrelated fillers. An additional set of 144 unrelated prime target pairs was created: 48 noun noun pairs, 48 noun pseudonoun pairs, 16 complex verb verb pairs, 16 complex verb pseudoverb pairs, 8 noun adjective pairs and 8 noun pseudoadjective pairs. Pseudowords were constructed by exchanging one or two letters in real words, while preserving the phonotactic constraints of German.

To summarize, a total of 264 prime target pairs was added as fillers. They were constructed in such a way that (a) half of the whole material set consisted of nouns (and some adjectives or adverbs), the other half of verbs; (b) half of the prime target pairs had words, the other half pseudowords as targets; (c) word pseudoword pairs constituted the same proportion of word categories (i.e., pseudo verbs, nouns, adjectives) as did the word word pairs. The large amount of fillers reduced the proportion of (d) critical prime target pairs to 15.6%, (e) semantically related prime target pairs to 7.8%, (f) form related word pairs to 10.4% and overall form related (word and pseudoword) pairs to 20.8% of the whole material set. All filler items differed from those of the critical set.

Apparatus

The apparatus was identical to that in Experiment 1.

Procedure

The related and unrelated primes of the same target were distributed over two lists. Each participant saw only one list and thus the same target word only once. Each list was divided into four blocks, each block containing the same number of stimuli per condition. The form related and meaning related prime pseudoword pairs and the remaining filler pairs were evenly allocated to the blocks. In total, an experimental session comprised 384 prime target pairs, 96 per block. Trial presentation within blocks was pseudo randomized separately for each participant, so that no more than four consecutive word or nonword targets occurred in a row. Sixteen additional prime target pairs were used as practice trials. The experimental procedure was identical to that used in Experiment 1. The duration of the experiment was approximately 25 min.

Results Experiment 3

Three (form related) items (*Mus*, *Karo*, *latschen*) were excluded from the analyses, since they were classified as nonwords by more than 40% of the participants. Outliers were treated as in the previous experiments: RTs exceeding 2000 ms or 3 standard deviations from a participant's mean were excluded (1.74% of the critical items). Mean response latencies were calculated for correct responses; mean error rate was 4.1% for the critical trials. Positively correlated RT and error means of the experimental conditions indicated that there was no speed accuracy trade off, $r(10) = .80629$, $p < .005$. All RT and error means are provided in Table 5.

Error data

A repeated measures logistic regression was run on accuracy data with 'factor' (morphological/semantic/form) and relatedness (related/unrelated) as main effects and participants as random intercept. In the following, significant effects only are reported. The main effect of 'factor' was significant, $F(2,6601) = 49.88$, $p < .001$, as was the interaction, $F(2,6601) = 9.66$, $p < .001$, indicating that relatedness increased the accuracy of the semantic factor (M S+F), $F(1,2220) = 9.83$, $p < .005$, while it decreased the accuracy of the form factor (M S F+), $F(1,2049) = 5.90$, $p < .05$.

Similar to the RT data, further repeated measures logistic regressions were run on the main effects of prime type (Morphological transparent/Morphological opaque/ Semantic verbs/Semantic nouns/Form verbs/Form nouns) and relatedness (related/unrelated) with participants as intercept. The main effect of prime type was significant,

Table 5
Mean response latencies and accuracies in Experiment 3 (Visual SOA 300).

Factor	RT (*SD*)	Effect	Error (*SD*)	Effect
Morphological M+S±F+				
Related	556 (96)	31***	2.3 (5.0)	(0.4)
Unrelated	588 (96)		2.7 (5.4)	
Transparent *vorlesen–lesen* (‘read to so.–read’)				
Related	553 (96)	29**	2.5 (5.1)	(0.3)
Unrelated	582 (96)		2.8 (5.6)	
Opaque *verführen–führen* (‘seduce– guide’)				
Related	560 (98)	35**	2.1 (4.9)	(0.5)
Unrelated	594 (96)		2.6 (5.2)	
Semantic M−S+F−				
Related	538 (83)	24***	1.0 (3.3)	1.5*
Unrelated	562 (86)		2.5 (4.9)	
Verbs *verlangen–fordern* (‘require– demand’)				
Related	561 (88)	28**	0.9 (2.9)	2.3*
Unrelated	589 (93)		3.2 (5.7)	
Nouns *Messer–Gabel* (‘knife–fork’)				
Related	514 (71)	22**	1.1 (3.6)	(0.7)
Unrelated	536 (69)		1.8 (3.8)	
Form M−S−F+				
Related	622 (100)	−19*	9.7 (8.9)	−2.7†
Unrelated	603 (88)		7.0 (8.9)	
Verbs *bekleiden–leiden* (‘get dressed –suffer’)				
Related	629 (102)	−17†	9.5 (8.4)	−3.6†
Unrelated	613 (97)		5.9 (8.0)	
Nouns *Bordell–Bord* (‘brothel– board’)				
Related	614 (98)	−21†	9.8 (9.5)	(−1.7)
Unrelated	593 (79)		8.1 (9.6)	

Note: Mean RTs in milliseconds (*SD* in parentheses) and mean percentage of errors (*SD*) for targets preceded by visually presented related primes and their matched unrelated controls. Primes were morphologically (M+S±F+), purely semantically (M−S+F−) or purely form-related (M−S−F+) with the targets. The morphological condition was further divided into semantically transparent (M+S+F+) and opaque (M+S−F+) derivations; the semantic condition into semantically related verb and noun pairs, and the form condition was divided into form-related verb and noun pairs. Priming effects are calculated relative to the matched unrelated controls. Nonsignificant effects are given in parentheses.
* $p < .05$ indicates significance levels for analyses by both participants and items.
** $p < .01$ indicates significance levels for analyses by both participants and items.
*** $p < .001$ indicates significance levels for analyses by both participants and items.
† $p < .05$ for either participants or items.

$F(5,6595) = 21.68$, $p < .001$, as was the interaction, $F(5,6595) = 4.27$, $p < .001$. Relative to unrelated controls, relatedness increased the accuracy of semantically related verbs, $F(1,1080) = 6.02$, $p < .05$, while it decreased the accuracy of form related verbs, $F(1,1024) = 6.55$, $p < .01$.

RT data

Analyses were performed on response latency with par ticipants (F_1) and items (F_2) as random variables. In the fol lowing analyses by participants (F_1), all variables were treated as repeated measures factors; in the analyses by items (F_2), relatedness was a repeated measures factor, all other factors were between items factors.

A two way ANOVA with ‘factor’ (morphological/seman tic/form) and relatedness (related/unrelated) indicated that the main effect of ‘factor’ was highly significant, $F_1(2,112) = 110.30$, $p < .001$, $F_2(2,114) = 25.27$, $p < .001$, as was the effect of relatedness, $F_1(1,56) = 12.34$, $p < .001$, $F_2(1,114) = 13.40$, $p < .001$. Importantly, the interaction was highly significant, $F_1(2,112) = 29.96$, $p < .001$, $F_2(2,114) = 18.57$, $p < .001$, and allowed us to scrutinize the priming effects in more detail.

Morphologically related primes (M+S±F+) significantly speeded responses relative to the unrelated condition, $F_1(1,56) = 44.18$, $p < .001$, $F_2(1,39) = 28.68$, $p < .001$. Semantically related primes (M S+F) also facilitated re sponses relative to the unrelated controls, $F_1(1,56) = 29.87$, $p < .001$, $F_2(1,39) = 20.05$, $p < .001$. By contrast, form related primes (M S F+) inhibited re sponses relative to the unrelated controls, $F_1(1,56) = 7.94$, $p < .01$, $F_2(1,36) = 6.49$, $p < .05$.

Since each of the above ‘factors’ (morphological/seman tic/form) comprised two conditions with two types of prime, we further conducted a two way ANOVA with fac tors prime type (Morphological transparent/Morphologi cal opaque/Semantic verbs/Semantic nouns/Form verbs/ Form nouns) and relatedness (related/unrelated) on la tency data. RT means are provided in Table 5. The effect of prime type was highly significant, $F_1(5,280) = 75.48$, $p < .001$, $F_2(5,111) = 15.84$, $p < .001$, as was the effect of relatedness, $F_1(1,56) = 12.34$, $p < .001$, $F_2(1,111) = 13.08$, $p < .001$. Again, the interaction was significant, $F_1(5,280) = 11.94$, $p < .001$, $F_2(5,111) = 7.30$, $p < .001$.

Both morphological conditions significantly speeded re sponses relative to their unrelated conditions: semanti cally transparent derivations (M+S+F+), $F_1(1,56) = 22.17$, $p < .001$, $F_2(1,19) = 14.52$, $p < .005$, and semantically opa que derivations (M+S F+), $F_1(1,56) = 20.60$, $p < .001$,

$F_2(1,19) = 13.71$, $p < .005$. Also semantic relatedness facilitated responses relative to the unrelated condition. This was true for semantically related verbs, $F_1(1,56) = 20.24$, $p < .001$, $F_2(1,19) = 10.72$, $p < .005$, and for semantically associated nouns, $F_1(1,56) = 12.32$, $p < .001$, $F_2(1,19) = 8.94$, $p < .01$. By contrast, form related nouns inhibited responses relative to the unrelated controls, though this effect was significant only in the analyses by participants, $F_1(1,56) = 5.57$, $p < .05$, $F_2(1,17) = 2.32$, $p = .146$. Form inhibition by verbs was marginally significant, $F_1(1,56) = 3.49$, $p = .067$, $F_2(1,18) = 4.83$, $p < .05$.

To compare the size of the priming effects, priming was calculated separately for each participant by subtracting the RT mean of the related prime condition from that of the matched unrelated condition. The priming effects (RT unrelated prime minus RT related prime) are depicted in the right panel of Fig. 1. A one way ANOVA with factor prime type (Morphological transparent/Morphological opaque/Semantic verbs/Semantic nouns/Form verbs/ Form nouns) was run on the difference scores. Post hoc comparisons (both Student Newman Keuls and Scheffé) indicated that the strength of the priming effects of all morphologically related (Morphological transparent/Morphological opaque) and semantically related (Semantic verbs/Semantic nouns) conditions were equivalent, but significantly differed from the two form conditions (Form verbs/Form nouns) which, in turn, did not differ significantly from each other.

Discussion

Experiment 3 was conducted to ensure that the observed morphological effects did not emerge due to methodological differences between our experiments and previous studies in English or French. Experiment 3 was thus constructed to test whether the morphological effects can be generalized under conditions that are very similar to those used previously in English or French: (a) prime types were manipulated across targets, (b) word classes were mixed, with half of them nouns and half verbs, (c) semantic pairs included noun associates of the *cello violin* type (in addition to semantically related verb pairs), and (d) form controls were of the *brothel broth* type and of the *replay lay* type and completely constituted the corresponding target either at the beginning or at the end, respectively.

The results were straightforward: the morphological effects were strong and unaffected by semantic transparency and thus replicated the results of Experiments 1 and 2. Unlike Experiments 1 and 2, the semantic effects were significant and as strong as the morphological effects, confirming that the main difference between German and other languages is not a matter of semantic priming, while form relatedness induced inhibition and thus confirmed that the morphological effects were not due to mere form overlap. We may thus conclude that the morphological effects no difference between priming from transparent and opaque complex verbs are genuine, since they arise under conditions that are sensitive to detecting both semantic and form influences and further generalize to different word classes.

General discussion

The focus of this series of experiments was on the lexical representation of morphologically complex verbs in German. Specifically, we explored the effects of morphological, semantic, and form relatedness between prime and target and what they reveal about the lexical representation of complex verbs. Since we aimed at exploring lexical representation, we applied an immediate unmasked priming paradigm that is sensitive to semantic processing and used overt prime presentations to make sure that the primes were consciously perceived. We tested whether lexical representation is guided not only by semantic composition but also by morphological structure. If morphological units affect lexical representation itself, morphological relatedness should affect target recognition independent of meaning and form relatedness. This is indeed what we found: alongside some unstable semantic and form effects, morphological relatedness facilitated target recognition under all modes of prime presentation. We thus provide evidence for the existence of a morphological dimension to lexical organization that cannot be reduced to formal or semantic relations between primes and targets. Most importantly, this indicates that morphological structure needs to be incorporated in the modeling of lexical representation in German.

Before we discuss the observed morphological effects and their consequences for theories of lexical representation in more detail, we will discuss some methodological issues concerning the effects of semantic and form relatedness on target recognition, since most models assume that either semantic relatedness alone (Marslen Wilson et al., 1994; Rastle et al., 2000) or both semantic and form relatedness strongly guide lexical representation (Gonnerman et al., 2007; Plaut & Gonnerman, 2000).

Semantic relatedness

In contrast to morphological priming, semantic priming was rather unstable across prime conditions: it showed almost nil facilitation in Experiments 1 and 2 (10 ms and 7 ms, respectively), but proved to be significant (24 ms) in Experiment 3, even when semantically related verbs (28 ms) and nouns (22 ms) are considered separately. Moreover, only in Experiment 3 was semantic facilitation (24 ms) statistically equivalent to morphological facilitation (31 ms, see Table 5).

In the case of verbs, both semantically related primes and semantically transparent derivations were synonyms of the base and thus carried similar meaning relatedness to the base. Furthermore, semantic association tests confirmed that purely semantically related primes (5.4 in Experiments 1 2 and 5.5 in Experiment 3) were rated as being as strongly meaning connected with the base as semantically transparent derivations (5.6 in Experiments 1 2 and 5.6 in Experiment 3). So any difference in effects between the two cannot be attributed to a difference in meaning relatedness between primes and targets, but rather stresses the impact of morphological facilitation.

Several recent studies on German verbs have indicated that semantic priming is generally hard to detect in behavioral data, with the number of nonsignificant effects (cf. Exp. 1 and 2 of the present study; Exp. 1 and 2a in Smolka et al., 2009, 2013; Zwitserlood et al., 1996) outnumbering the significant ones (cf. Exp. 3 of the present study; Exp. 1 in Smolka, 2012; Exp. 2b in Smolka et al., 2009). Table 6 summarizes the semantic effects that have been observed so far in seven experiments on German complex verbs and whether or not they are comparable to the morphological effects in the same experiment. The table further differentiates between methodological factors, such as prime modality, SOA, within or between subjects design, target manipulation, and type of materials. However, there is no obvious pattern that indicates which factors determine whether or not semantic facilitation reaches significance.

Most importantly, we have shown that our morphological effects are very robust and survive experimental conditions that favor semantic influences. What do the semantic effects tell us about the lexical representation of complex verbs in German? The fact that the semantic activation between verbs relating to different bases is less stable than that between verbs relating to the same base even if these are NOT semantically related indicates that the network is related via base forms rather than via pure semantic/meaning association. We will return to this issue below.

Form relatedness

In contrast to semantic relatedness, form relatedness generally hindered target recognition although its strength varied with the experimental design: form inhibition was significant under cross modal priming (12 ms) and under visual priming with across target manipulations (19 ms); this also held when verbs (17 ms) and nouns (21 ms) were considered separately. Form inhibition was not significant, though, under visual prime presentation with within target manipulations (9 ms), thus replicating nonsignificant effects of two previous experiments with visual prime presentation (Smolka et al., 2009; see Table 6). Table 6 summarizes the different form effects of our recent experiments and indicates that form inhibition is particularly strong under cross modal priming and under across target manipulations. Across target manipulations were mostly used in previous studies in other languages, where form relatedness of the prime generally hindered target recognition, but not necessarily in statistically significant ways. This holds for prime conditions similar to those in Experiments 1 and 3 of the present study, namely visual priming at SOAs of 230 ms or more (Drews & Zwitserlood, 1995; Feldman, 2000; Grainger, 1990; Pastizzo & Feldman, 2002; Rastle et al., 2000; Segui & Grainger, 1990), as well as for prime conditions similar to those in Experiment 2, namely cross modal priming (Marslen Wilson et al., 1994; Pastizzo & Feldman, 2002).

Form controls in Experiments 1 and 2 of the present study (as well as those in Smolka et al., 2009) changed a letter in the verb stem, as in *zerfließen fliegen* or *abbilden binden*. They thus possessed similar or even higher letter overlap with the targets than form controls used in some previous studies in English where targets changed the vowel and/or consonants of the prime, as in *body bid*, *life louse*, *space speak* (cf. Appendix A and C in Crepaldi, Rastle, Coltheart, & Nickels, 2010) or shared some letters with the prime either at its beginning or at its ending, as in *button butter* or *claret ferret*, respectively (cf. Appendix B in Rastle et al., 2000).

Be that as it may, the letter overlap in the form conditions of our Experiments 1 and 2 was less than that in the two morphological conditions where the primes completely comprised the targets. To provide for a comparable letter overlap in the form condition, we introduced two types of form controls in Experiment 3 where the target is completely embedded in the prime. One subtype was comprised of verbs of the *replay lay* type, the other subtype was modeled on form controls in previous English experiments and used orthographic controls of the *broth*

Table 6
Summary of semantic (M−S+F−), semantically transparent (M+S+F+), semantically opaque (M+S−F+), and form (M−S−F+) effects from the present and previous studies (Smolka, 2012; Smolka et al., 2009).

Study	Exp.	Design	Target manipulation	Materials	Modality	SOA	M−S+F−		M+S+F+		M+S−F+	M−S−F+
Present	2	Within	Within	Verbs	Auditory	100	$(7)_S$	<	26^{**}	=	17^{**}	-12^{**}_L
Present	1	Within	Within	Verbs	Visual	300	$(10)_S$	<	28^{**}	=	25^{**}	$(-9)_L$
2009	1	Within	Within	Verbs	Visual	300	$(0)_{A+S}$	<	30^{*}	=	43^{*}	–
2009	2a	Within	Within	Verbs	Visual	300	$18^{\dagger}_{A+S}$	<	36^{**}	=	36^{**}	$-14^{\dagger}_L$
2012	1	Between	Within	Verbs	Visual	500	15^{*}_S	<	61^{**}	=	58^{**}	$(5)_L$
Present	3	Within	Across	Mixed	Visual	300	28^{**}_S	=	29^{**}	=	35^{**}	-17^{*}_E
2009	2b	Within	Within	Verbs	Visual	1000	30^{**}_{A+S}	=	37^{**}	=	28^{**}	$(-11)_L$

Note: Design refers to within- or between-subjects design; target manipulation refers to whether the same (within) or different (across) targets were used across conditions; materials comprised either verbs only or mixed word classes; target presentation was always visual; modality of the prime was either auditory or visual at different stimulus onset asynchronies (SOA); A = semantic associates; S = synonyms; L = letter change in the stem, as in *erziehen–zielen*; E = target completely embedded in the prime, as in *bekleiden–leiden*. Effects were calculated relative to an unrelated baseline; </=/> indicate statistical differences between the effects of semantic associates or synonyms (M−S+F−) and semantically transparent derivations (M+S+F+), as well as between the effects of semantically transparent and opaque (M+S−F+) derivations. Form (M−S−F+) effects are provided separately; nonsignificant effects are given in parentheses.

† Effects of the study of Smolka et al. (2009) are taken from the first-block analyses (without target repetition), those effects that reached significance due to target repetition only.

* $p < .05$ indicates the significance level for analyses by participants or items.

** $p < .05$ for analyses by both participants and item.

el broth type. This design further made it possible (similar to the two semantic conditions) to differentiate between noun and verb pairs. Again, we found strong morphological facilitation alongside form inhibition and may thus conclusively rule out that form relatedness contributed to the morphological effects.

Overall, with respect to these relatively small and unstable (significant and nonsignificant) semantic and form effects, we may conclude that the morphological effects we obtained with German complex verbs cannot be reduced to pure semantic and form relatedness between words.

Morphological relatedness

In contrast to semantic and form relatedness, morphological relatedness strongly facilitated target recognition under all prime presentation modes and was not affected by semantic transparency. That is, semantically opaque complex verbs produced the same amount of priming as did semantically transparent verbs: 25 ms vs. 28 ms, respectively, in Experiment 1, 17 ms vs. 26 ms in Experiment 2, and 35 ms vs. 29 ms in Experiment 3. Taken together with our previous findings (Smolka, 2012; Smolka et al., 2009; see also Table 6), we have in fact evidence from seven data sets: six visual and one cross modal. Unequivocally, all show that morphological structure determines word recognition.

Affixation type

One might argue that the origin of the strong morphological effects (without effects of semantic transparency) in our study arose due to the use of prefixed words. Indeed, most overt priming studies so far examined suffixed derivations. Nevertheless, a few have used prefixed prime target pairs that are similar to those used in the present study. For example, Experiment 4 in Marslen Wilson et al. (1994) compared semantically transparent and opaque prefixed words of the type *disobey obey* and *restrain strain*, respectively, and observed priming from the former but not from the latter. Since that experiment was conducted under cross modal priming conditions, it is in fact very similar to the cross modal experiment (Experiment 2) of the present study, in which we observed strong effects by semantically opaque pairs of the *understand stand* type.

Furthermore, in an Experiment with Serbian prefixed words, only semantically transparent (*privole volim*) but not semantically opaque (*zavole volim*) words induced priming (cf. Experiment 1A in Feldman et al., 2002). Since that experiment was conducted under visual priming at 250 ms SOA, it is similar to Experiments 1 and 3 of the present study, where we used visual priming at 300 ms SOA and did observe priming due to opaque prefixed derivations.

Further, a study in Dutch explored whether sentence primes facilitated the recognition of semantically transparent or opaque prefixed verbs (Zwitserlood, Bolwiender, & Drews, 2004). Again, semantically transparent and ambiguous verbs were primed, while truly opaque prefixed verbs were not. Although this study applied a different experimental design, it still provides evidence for a processing difference between semantically transparent and opaque prefixed words, which contrasts with the findings of the present study.

By contrast, only one other study on German prefixed verbs found morphological priming from semantically opaque verbs (Drews et al., 2000). Altogether, studies that used prefixed words in languages other than German have not found morphological priming from semantically opaque words. We can thus be sure that it is not the affixation type that caused the morphological priming effects. What may seem peculiar with regard to single word presentations will be more compelling if we consider natural language settings.

Productivity

First, the productivity of prefixed derivations in German is extremely high. A single base verb may yield families of up to 150 prefixed verb derivations, all with different meanings ranging from truly transparent to truly opaque. For example, the German base *stehen* (‘stand’) has more than 100 prefixed derivations, while the same base *stand* in English possesses the prefixed derivations *understand* and *withstand* and about 20 phrasal verbs (cf. McCarthy & et al., 2006). Furthermore, any complex verb is conjugated in exactly the same way as its base verb (i.e. with the same irregularities, if there are any) and thus keeps the link to its origin. Due to the high number of family members, German speakers may thus be more responsive to the base than speakers of English.

The productivity of German verbs may lead to a generalization of (morphological) form that becomes relatively independent of meaning relatedness, as is the case in root languages like Hebrew and Arabic. Indeed, connectionist accounts suggest that whether one finds non semantic morphological priming depends on the morphological structure of the language as a whole (cf. Plaut & Gonnerman, 2000). In a morphologically rich language where mappings between form and meaning are straightforward, morphological regularities will dominate language processing so that priming effects will extend to semantically opaque items (Plaut & Gonnerman, 2000). Indeed, the form meaning network suggested by Plaut and Gonnerman was able to simulate morphological activation for semantically opaque items in a rich artificial input language. Nevertheless, it could not simulate the absence of a semantic transparency effect, as would be necessary to simulate our findings in German.

Particle separation

Because German is a verb second language with an SOV word order (e.g., Haider, 1985), particle verbs in German are decomposed whenever they occur in finite forms. In contrast to English, where the particle of a phrasal verb may or may not be separated by a noun phrase, in German the particle must appear sentence final. Hence, an almost infinite amount of material may be inserted in between the finite verb and its particle, ranging from complex noun phrases to relative clauses. So the particle, which must complement the meaning of the whole complex verb, can be presented many words after the stem, as the following example of a semantically transparent and opaque deriva tion of the base *kommen* ('come') demonstrates: 'Sie *kam* nach einer Indienreise, auf der sie sich mit Malaria infizierte hatte, schließlich in ihrem Heimatort *an/um*' (L: 'Finally, she *arrived/died* in her hometown after having infected herself with malaria on a trip to India'). This presumably means that German readers/listeners are used to keeping more than one possible meaning of the verb active upon encountering a verb stem.

Lemma frequency

Placing the main verb in second sentence position and the particle in sentence final position may not only strain the memory load of German speakers. It has a methodological effect as well: German lexical databases like CELEX (Baayen et al., 1993) and dlexDB (Heister et al., 2011) do not count particle verbs if the particle is separated and occurs at the end of the sentence. Since this occurs in all main clauses in the present, preterit and imperative, frequency counts of particle verbs in German powerfully underestimate the particle forms and overestimate the base forms. The most recent database dlexDB, for example, lists only those tokens of a particle verb where the particle is not separated from the finite verb. This handicap of lemma counts needs to be kept in mind. We are thus confident that the complex verbs in our study are well known and frequently used verbs, even if their lemma frequencies (about 6 7 per million, see Tables 1 and 4) are lower than those in other experiments with either prefixed primes in English (between 9 and 51 per million in Experiments 4 6 in Marslen Wilson et al., 1994) or with suffixed primes in French (about 12 per million in Longtin et al., 2003).

To make sure that frequencies are well matched across prime conditions, we further matched particle verbs on word form frequencies, where the lexical databases provide correct counts (see Tables 1 and 4).

Morphological richness

Interestingly, strong morphological effects (without form effects and independent of semantic effects) have been so far observed in Hebrew, Arabic, and German, providing evidence that lexical representation in these languages is guided by morphological structure. Indeed, like Semitic languages, German is considered morphologically rich among the Indo European languages. Differences in morphological richness between Germanic languages such as English, Dutch, and German may result from typological differences that emerged during language history (Roelcke, 1997). In synthetic languages like Proto Germanic, grammatical relations were dominantly marked by morphology (hence 'morphologically rich'). During language history, analytic languages developed a tendency to reduce morphological markedness (hence 'morphologically impoverished') and express grammatical relations rather by syntax, such as by a stricter word order (De Vogelaer, 2007). In this sense, English has been the most innovative in developing syntactic markers for expressing grammatical functions, whereas German has been the most conservative Germanic language, keeping morphological markers to indicate grammatical functions. In this sense, German is also 'morphologically richer' than other Indo European languages like Spanish and French, as it uses gender and case markers in the inflectional noun system, as well as complex verbs and more productive systems of compounding. For example, particles and prefixes of German complex verbs express the functions of adverbs of place, time, and manner in more analytic languages. Morphological richness the use of morphology to express syntax is a language characteristic that makes German more similar to Semitic languages like Hebrew and Arabic than to Indo European languages.

Most psycholinguistic models of lexical representations usually assume that what is true of one language is true of all. However, our results argue for cross language differences in morphological processing and hence also in lexical representations. As we described above, there are several features of German in general (e.g., morphological richness, V second language; SOV word order) and of complex verbs in particular (e.g., productivity; particles at sentence final position) that differentiate German from both other Indo European and Semitic languages and may cause the strong morphological effects we observed. Any assertion, though, as to which of these features or feature combinations is responsible for German lexical representations occurring via the base is speculative.

We thus want to stress the importance of cross language and cross linguistic evidence in building models of lexical representations. We assume that the peculiarities of German particle verbs train native speakers to generalize the morphological form above and beyond the meaning of a particular whole word derivation. Morphological structure strongly affects lexical representation in German and needs to be incorporated in modeling lexical representation: a German verb like *understand* is represented as the base {stand} and the prefix/particle {under}. Most of the above mentioned pre and supralexical models cannot incorporate the present findings in German, especially not those regarding opaque morphological effects under auditory prime presentation. In the following, we adapt the frequency based model previously suggested by Smolka and colleagues (for details see Smolka, 2005; Smolka et al., 2009; Smolka, Zwitserlood, et al., 2007); see Fig. 2.

The model assumes segmentation processes similar to those suggested by models of prelexical processing. The findings of the cross modal experiment of the present study indicate that morpho phonological segmentation in auditory word recognition provides similar mappings to those that result from morpho orthographic segmentation in visual word recognition. That is, German strings like *zubinden* ('tie') and *entbinden* ('deliver') are segmented into their constituent morphemes regardless of meaning compositionality: *zu* , *ent* , *bind*, *en*. These constituents activate their representations at the lexical level. Hence, both the transparent verb *zubinden* and the opaque verb *entbinden* are lexically represented via their base {bind} and {en}, and constituents {zu}, and {ent}, respectively. Since the target *binden* ('bind') activates the same lexical units {bind} and {en}, its recognition is facilitated by the prior presentation of a complex verb with the same base. This accounts for the findings of the present study that the activation of morphologically related words is independent of meaning compositionality. Furthermore, the finding that semantically opaque verbs induce the same amount of facilitation

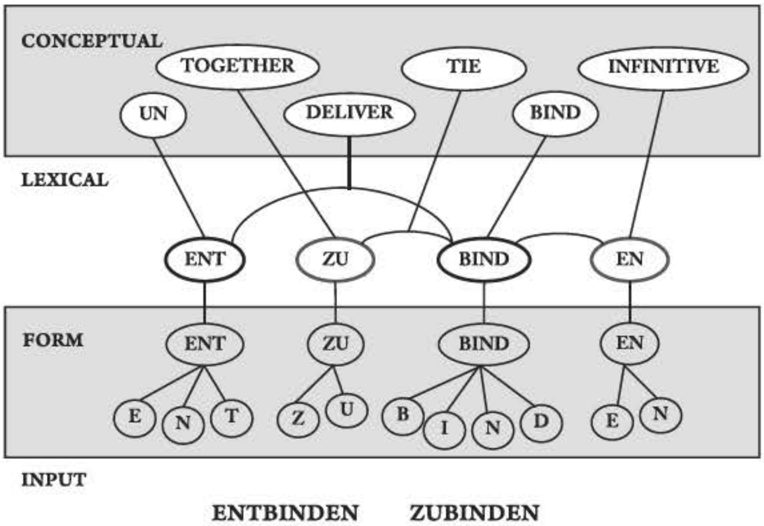

Fig. 2. An adapted frequency-based model to capture the features responsible for lexical representations of semantically transparent and opaque derivations occurring via the base (see text for further details).

as transparent ones indicates that the stems were accessed before the meaning of the whole word, which contradicts the assumptions of a supralexical model (e.g., Giraudo & Grainger, 2000).

With respect to the structure of the lexical representa tions, the equivalent effects of semantically transparent and opaque conditions under cross modal priming in Experiment 2 have shown that we are dealing with both modality specific and modality abstract lexical represen tations (see Rueckl & Galantucci, 2005).

How is the specific word meaning derived? The lexical entries of the base and constituents directly activate their corresponding concepts at the conceptual level: TO GETHER, UN(DO), BIND, and INFINITIVE, respectively. In addition, the particular concepts TIE and DELIVER are acti vated by the co activation of the specific constituents at the lexical level ({zu} and {bind}; {ent} and {bind}, respec tively). The idea that the simultaneous activation of several constituents at the lexical level may activate some idiosyn cratic concept is not novel. Models of idiomatic processing assume that the meaning of idioms is activated by the simultaneous activation of the constituents, whether di rectly (e.g., Rabanus, Smolka, Streb, & Rösler, 2008; Smolka, Rabanus, & Rösler, 2007) or indirectly via '*superlemmas*' or similar constructions that represent the idiomatic meaning in addition to that of the single constituents (e.g., Kuiper, van Egmond, Kempen, & Sprenger, 2007; Sprenger, Levelt, & Kempen, 2006). That is, the figurative meaning of an idiom is lexically represented and processed via its parts. If we keep in mind that even semantically transparent der ivations yield specific idiosyncratic concepts from the meaning of the base and the function of the prefix, the lex ical representation of verb derivations more or less idio syncratic in meaning may function in similar ways.

We may thus assume that transparent and opaque meanings are generated in similar manners. This can be achieved by assuming separate whole word lemmas (e.g. similar to 'superlemmas' in idiom processing). In the fre quency model, the specific meanings are selected by mech anisms that rely only on connections between lexical and conceptual units, selecting the most frequently activated concept upon the co activation of the constituents. Hence, the stem affix combination *bind* (bind) and *zu* (together) will activate the transparent concept TIE, while the stem affix combination *bind* (bind) and *ent* (un) will acti vate the opaque concept DELIVER. Note that both concepts differ from the concept BIND of the single constituent.

In sum, our findings indicate that lexical representation in German refers to the base of a complex verb, regardless of meaning compositionality in form of both modality spe cific and modality abstract representations. This indicates that morphological structure represents an important as pect of language processing in German and must be incor porated in the lexical representation of German words.

It is possible that different languages vary in the extent to which they drive the development of such a representa tional level. This leads to the question of whether different models for different languages are needed, or whether a 'universal' model can be developed that encompasses all linguistic variations (for a recent debate that focuses on reading models see Frost, 2012, and the corresponding peer commentaries). This question has been recently raised by Frost and colleagues (e.g., Bick, Goleman, & Frost, 2011; Frost, 2009, 2012) in terms of the "ecological view", stating that even though some language characteristics are universal, the specific linguistic properties of a given lan guage modulate the way it is processed. This view may well describe the situation with our data in German: Even though German shares many features with other Indo European, and in particular Indo Germanic languages, spe cific properties drive the development of a representa tional level that encompasses morphological structure. Settling this question will require cross linguistic compar isons in future studies.

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A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jml.2013.12.002.

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