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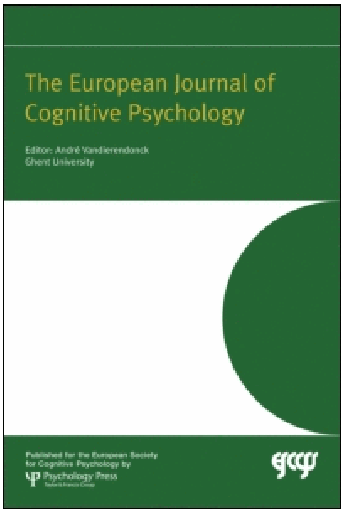

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Adore-able not adorable? Orthographic underspecification studied with masked repetition priming

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Adore-able not adorable? Orthographic underspecification studied with masked repetition priming

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This paper reports three masked priming experiments examining morphological priming with nonword primes, using targets that were incompletely represented in the primes due to a missing "e" at the morpheme boundary (e.g., adorage-adore). Primes were constructed with a vowel-initial suffix (e.g., adorage) in the first experiment and with a consonant-initial suffix (e.g., adorly) in the second experiment. Priming was observed in both experiments relative to an orthographic control condition. Experiment 3 was a control experiment designed to show that targets in the morphological and orthographic form conditions of the first two experiments were equally susceptible to priming. Overall, our findings provide support for a form of morphemic decomposition that is based on the mere appearance of morphological complexity (e.g., Rastle, Davis, & New, 2004), and demonstrate that this form of morphemic decomposition is robust to regular orthographic alterations that occur in morphologically complex words.

Keywords: Morphology; Visual word recognition; Masked priming; Morphologically complex pseudowords.

It is well established that the recognition of a printed stem target (e.g., govern) is speeded by the prior presentation of a visually presented morphologically-related prime (e.g., government) relative to an unrelated control prime (e.g., brightness). This morphological priming effect has been reported across languages (e.g., English: Rastle, Davis, Marslen-Wilson, &

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Tyler, 2000; French: Giraudo & Grainger, 2000; German: Drews & Zwitserlood, 1995; Spanish: Badecker & Allen, 2002; Hebrew: Deutsch, Frost, & Forster, 1998; Arabic: Boudelaa & Marslen-Wilson, 2001) and is usually argued to implicate a process whereby the morphologically complex prime is decomposed into its constituent morphemes (e.g., {govern} + {-ment}). Morphological priming effects are thought to arise because this decomposition process permits the prior activation of a lexical representation for the stem target thus facilitating its later recognition.

Until recently many researchers thought of morphological decomposition as a high-level phenomenon constrained by semantic knowledge (Marslen Wilson, Tyler, Waksler, & Older, 1994). However, recent research using the masked priming paradigm in which primes are presented extremely briefly (e.g., 40 ms) has posed a significant challenge to this position. Under these brief exposure conditions, researchers have observed significant and equivalent priming effects on visual lexical decision for semantically related (e.g., darkness-DARK) and pseudomorphological (e.g., corner-CORN) pairs. These facilitative effects are greater than those obtained for pairs that have only a nonmorphological form relationship (e.g., brothel-BROTH), indicating that they are not the result of simple letter overlap (Longtin, Segui, & Halle, 2003; Rastle, Davis, & New, 2004; see Rastle & Davis, in press, for a review). The fact that robust priming effects are obtained for pairs like corner-CORN indicates that morphological decomposition is insensitive to semantic characteristics, and instead suggests that decomposition is based on the *mere appearance* of morphological structure (Rastle & Davis, 2003; Rastle et al., 2004). Hereafter we refer to this as "morpho-orthographic decomposition" (after Rastle et al., 2004).

The research presented in this paper focuses on an important prediction of this proposal, namely that if morphological decomposition is based on the mere appearance of morphological complexity, then it should be evident for nonwords comprising a morphological structure (e.g., habitness, darkify). Longtin and Meunier (2005) investigated this prediction in a series of masked priming experiments that used French nonword primes comprising either syntactically legal (e.g., rapidifier-RAPIDE) or syntactically illegal (e.g., sportation-SPORT) morphological combinations (analogous examples in English would be quickify-QUICK and spendical-SPEND, respectively). They found that both of these types of morphologically structured nonword primes yielded facilitation on the recognition of stem targets (relative to an unrelated baseline), and that this facilitation was of a magnitude equal to that observed when primes were semantically transparent derived words (e.g., rapidement-RAPIDE). It was argued on the basis of a series of comparisons that the priming effects being observed were due to the apparent morphological overlap between primes and targets and not due to the orthographic similarity between primes and targets (but see later).

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One problem with the work reported by Longtin and Meunier (2005) is that it did not demonstrate directly that the facilitation yielded by morphologically structured nonword primes was *greater* than that yielded by nonmorphological form controls. Observing a significant effect across this contrast is necessary if one wishes to argue convincingly that the priming effects yielded by morphologically structured nonwords were not the result of simple orthographic overlap between primes and targets. Longtin and Meunier (2005) instead made an inference to this effect by showing (a) that morphologically structured nonword primes and semantically transparent derived primes yield equivalent facilitation; (b) that semantically transparent derived primes yield significantly more facilitation than nonmorphological form primes; and (c) that priming from nonmorphological form primes is not statistically reliable. Unfortunately, it is possible for all three of these conditions to be met in the absence of the necessary difference between priming from morphologically structured nonwords and priming from nonmorphological form controls. Because of this difficulty, and because the evidence for morpho-orthographic decomposition using French word primes has not always been reliable (see Diependaele, Sandra, & Grainger, 2005 who failed to replicate the original Longtin et al., 2003, study), further investigation of this issue is required. The first aim of our research is therefore to determine more convincingly whether morphologically structured nonwords are decomposed into their constituents during the initial stages of visual word recognition.

The second aim of our research is to determine whether the decomposition process for these morphologically structured nonwords breaks down when they cannot be parsed perfectly into stem and affix combinations due to a missing letter at the morpheme boundary (e.g., "adorage" cannot be parsed perfectly into "adore" and "-age"). McCormick, Rastle, and Davis (2008) recently explored this issue in respect of the masked priming effects observed for morphologically complex words. They compared masked priming effects for semantically transparent morphological pairs that could be parsed perfectly into their constituent morphemes (e.g., darkness-DARK) with masked priming effects for three sorts of semantically transparent morphological pairs that could not be parsed perfectly into their constituent morphemes because of (a) a missing "e" at the morpheme boundary (e.g., adorable-ADORE), (b) a shared "e" at the morpheme boundary (e.g., writer-WRITE), or (c) a duplicated consonant at the morpheme boundary (e.g., metallic-METAL). Priming effects in these morphological conditions were compared with those in a matched, nonmorphological form condition (e.g., brothel-BROTH). Significant and equivalent priming effects were obtained for all morphologically related pairs irrespective of the presence or type of orthographic change included in the morphologically complex primes. Further, these priming effects were consistently larger than those observed in the nonmorphological form condition. McCormick et al. (2008) explained these results in terms of the underspecification of stems that regularly undergo orthographic alterations (a proposal originally introduced by Taft, 1979), arguing that such stems may be represented orthographically such that surface variations can be tolerated once a suffix is segmented from the stimulus (e.g., by marking a final "e" as optional).

On the proposal laid out by McCormick et al. (2008), morpho-orthographic decomposition should be robust to regular orthographic alterations (e.g., a missing "e" at the morpheme boundary) irrespective of the lexical status of the morphologically structured stimulus. Provided that a particular stem is stored in an underspecified manner (e.g., ADORE being represented as having an optional final "e"), it should not matter whether the morphologically structured stimulus is a word (e.g., adorable) or a nonword (e.g., adorage). In both cases the suffix will be segmented from the prime stimulus through the morpho-orthographic decomposition process, leaving a partial stem that activates the (underspecified) orthographic representation of the target. Thus, we would expect to observe robust masked priming effects for pairs like adorage-ADORE, despite the fact that the stem component of the prime is not an exact match to the target. Though this hypothesis follows straightforwardly from the work of McCormick et al. it is important to remember that their proposal was based primarily on the results of masked priming studies using semantically transparent derived words as primes (e.g., adorable-ADORE). Investigating whether the segmentation of morphologically structured nonwords survives orthographic alteration thus represents a particularly strong test of their proposal.

One interesting additional question is whether the nature of the suffix in these cases of orthographic alteration influences the priming effects observed. Specifically, the vast majority of "e" deletions in morphologically complex words arise when the suffix begins with a vowel (e.g., adoring, adorable). Indeed, out of the entire corpus of morphologically complex words having a stem + suffix structure (as described in the CELEX database; Baayen, Piepenbrock, & van Rijn, 1993), there are less than 20 instances in which a stem-final "e" is deleted prior to a consonant-initial suffix (e.g., argument, fledgling, ninth, truly, width, wisdom). It therefore seems possible that a vowel-initial suffix (e.g., -age, -ist, -able) may be required to "licence" the recognition system to accept a partial stem (e.g., ador) as a satisfactory match to an existing lexical entry. The third aim of this research is therefore to determine whether masked priming effects for pairs like adorage-ADORE are maintained when the suffix used does not begin with a vowel (e.g., adorful-ADORE).

The final aim of our research concerns the extent to which the underspecification of stems that frequently occur in orthographically altered contexts (e.g., adore) may generalize to stems that never occur in

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orthographically altered contexts (e.g., olive). It seems plausible that if a stem never occurs in a context in which its final "e" is deleted, then it may not be stored in a manner in which its final "e" is marked as optional. However, it is also possible that all stems with a final silent "e" are stored in an underspecified manner (Taft, 1979). The study by McCormick et al. (2008) yielded some (albeit limited) evidence in favour of the latter possibility. In their final experiment they observed robust masked priming effects for pseudoaffixed primes that contained regular orthographic alterations such as missing "e" (e.g., fetish-FETE). Critically, only some of these targets ever occurred in orthographically altered contexts (e.g. FETE never occurs in a context in which its "e" is deleted). Nevertheless, a post hoc analysis revealed no difference in the priming effects observed for targets that do and do not occur in orthographically altered form. Our study seeks to investigate this issue more fully.

Overall, the research presented in this article had four aims: (1) to establish more convincingly whether morpho-orthographic decomposition arises for morphologically structured nonwords; (2) to establish whether this decomposition is robust to regular orthographic alterations in morphologically structured nonwords; (3) to establish whether this robustness to orthographic alteration requires a vowel-initial suffix; and (4) to establish whether this robustness to orthographic alteration is maintained in the case of stems that never surface in orthographically altered form. We sought to meet these aims through three masked priming experiments that investigated the priming effects resulting from various kinds of morphologically structured nonword primes against the priming effects resulting from appropriately matched nonmorphological form controls.

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EXPERIMENT 1

Experiment 1 sought to address the first, second, and fourth aims just described. It examined whether masked priming effects are observed for morphologically structured nonword primes with a missing "e" at the morpheme boundary, and critically, whether these effects are larger than those observed as a result of nonmorphological form overlap. It also tested whether these effects are diminished when the stems used never occur in orthographically altered contexts. Morphological primes in this experiment were constructed in the "typical" manner, with the "e" deletion being followed by a vowel-initial suffix (e.g., adorage).

Method

Participants. The participants were 82 volunteers from Royal Holloway, University of London. Participants had normal or corrected-to-normal vision and were native speakers of English. They were offered £5.00 in exchange for their time.

Stimuli. One hundred and twenty prime–target pairs were constructed, forty in each of three conditions. The first two conditions comprised morphologically structured nonword primes with an "e" deletion followed by (a) targets ending in "e" that occur frequently with an "e" deletion (e.g., "adore", hereafter referred to as "optional e" items) or (b) targets ending in "e" that never occur with an "e" deletion (e.g., "olive", hereafter referred to as "obligatory e" items). Morphological primes were all syntactically illegal (i.e., they used suffixes that could not legally attach to their respective stems), and used a range of frequently occurring vowel-initial suffixes. The third condition comprised prime–target pairs with a nonmorphological form relationship. Primes in this condition comprised a target minus its final letter plus a nonmorphological ending (e.g., bliston-BLISS).

Targets were matched as closely as possible on frequency, neighbourhood size, and length. Each target had a minimum frequency of 18 per 17.9 million and a maximum neighbourhood size of 6. Primes across the conditions were matched on length and overlap with the target (expressed as "number of target letters"/"number of prime letters"). Stimulus characteristics are described quantitatively in Table 1.

Unrelated control primes were constructed for each of the 120 target words. They were matched pairwise on length and groupwise on stem frequency and stem neighbourhood size to the related primes. Unrelated

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TABLE 1
Stimulus characteristics (means and statistical test data) for targets and primes in Experiments 1–3

	Optional "e"	*Obligatory "e"*	*Form*	*ANOVA*
Target characteristics	ADORE	OLIVE	BLUNT	
Target frequency	40	31	34	$F(2, 119) = 0.121$, *ns*
Neighbourhood size	2.25	2.65	2.58	$F(2, 119) = 0.487$, *ns*
Target length	5.075	5.05	5.05	$F(2, 119) = 0.023$, *ns*
Prime characteristics	adorage	olivant	blunana	
Experiment 1				
Prime length	7.15	7.20	7.90	$F(2, 119) = 0.053$, *ns*
Overlap	0.57	0.56	0.43	$F(2, 119) = 0.317$, *ns*
Prime characteristics	adorment	olivment	blunana	
Experiment 2				
Prime length	7.80	7.90	7.90	$F(2, 119) = 0.015$, *ns*
Overlap	0.52	0.51	0.52	$F(2, 119) = 0.408$, *ns*
Prime characteristics	ador	oliv	blun	
Experiment 3				
Prime length	4.10	4.05	4.05	$F(2, 119) = 0.094$, *ns*

primes always used the same suffix or nonmorphological ending as did the related primes.

Forty pairs of totally unrelated primes and targets were added to the stimulus set in order to reduce the overall relatedness proportion to 37%. These filler targets were groupwise matched to the experimental targets on frequency, length, and neighbourhood size. Filler primes were groupwise matched on length to the experimental primes.

One hundred and sixty morphologically simple nonword targets were selected for the "no" response of the lexical decision task. Nonword targets were groupwise matched to the experimental and filler targets on length and neighbourhood size. These nonword targets were preceded by unrelated nonword primes that were a mixture of morphologically structured and morphologically simple nonwords. Nonword primes were groupwise matched to experimental/filler primes on length.

Targets from each condition were divided at random into two equal lists for counterbalancing purposes, with half of the targets in each list preceded by related primes and half by unrelated control primes. Participants received only one experimental list and therefore participated in all priming conditions but saw each target word only once. Including the experimental, filler, and nonword trials, each participant made 320 lexical decisions. Test stimuli for this experiment are presented in Appendix A.

Apparatus and procedure. Stimulus presentation and data recording were controlled by the DMDX software (Forster & Forster, 2003) running on a Pentium III personal computer. A two-button response box was used to record lexical decisions, in which the YES response button was controlled by the dominant hand.

Participants were tested in a dimly lit, quiet room. They were advised that they would be seeing a series of letter strings presented one at a time, and that they would be required to decide as quickly and accurately as possible whether each string was a word or not a word. Participants were not told of the existence of the prime stimulus. Primes were presented in lower case for 42 ms.[1] These primes were preceded by a 500 ms forward mask (consisting of hash marks) and were followed immediately by a target in uppercase that remained on screen until a response was made or until 6 s had elapsed.

[1] The use of such a brief prime duration follows other studies in which morpho-orthographic effects have been observed (Gold & Rastle, 2007; Lavric, Clapp, & Rastle, 2007; Longtin & Meunier, 2005; Longtin et al., 2003; Rastle et al., 2000Rastle et al., 2004). There is considerable evidence that the pattern of effects changes (such that a semantically based form of decomposition is observed) at longer prime exposure durations (Meunier & Longtin, 2007; Rastle et al., 2000; see Rastle & Davis, in press).

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Targets were presented in a different random order for each participant. Participants were given 10 practice trials before beginning the experiment.

Results

RT and error data were cleaned to remove outlying participants, items, and individual data points. Participants in all experiments were excluded if they had an average nonword RT over 1400 ms, a nonword false positive rate over 40%, an average target RT over 1000 ms, or a target error rate over 30%. Items with error rates over 45% were also removed from the analysis. These criteria led to the exclusion of the target TRITE from the analysis. The remaining data points were then plotted and 69 outliers over 1950 ms (0.74% of the data) were removed.[2] Data in all experiments were then subjected to an inverse transformation before analysis in order to reduce the influence of any remaining outliers (Ulrich & Miller, 1994). Means in the text and tables are retransformed as harmonic means, however, in order to show differences between experimental conditions clearly.

Data were analysed both by subjects and by items using three-factor ANOVAs. The analysis by subjects treated priming (two levels) and condition (three levels) as repeated factors and list (two levels) as an unrepeated factor. The analysis by items treated condition and list as unrepeated factors and priming as a repeated factor. Latency and error data for Experiment 1 are shown in Table 2.

The ANOVAs on the latency data revealed an interaction between condition and priming that was significant by subjects and by items, $F_1(2, 160) = 8.31$, $p < .01$; $F_2(2, 113) = 7.03$, $p < .01$. In order to investigate the source of this interaction, *t*-tests were used to establish the amount of priming within each condition. There was robust priming in the optional "e" condition, $t_1(81) = 7.21$, $p < .001$; $t_2(39) = 6.87$, $p < .001$, and in the obligatory "e" condition, $t_1(81) = 3.78$, $p < .001$; $t_2(38) = 3.55$, $p < .001$, but not in the nonmorphological form condition, $t_1(81) = 0.81$, *ns*; $t_2(39) = 1.56$, *ns*. Comparisons of the priming effects between conditions confirmed that priming effects were larger in the optional "e" condition than in the orthographic form condition, $t_1(81) = 4.19$, $p < .001$; $t_2(78) = 3.86$, $p < .001$. Priming effects in the optional "e" condition were marginally larger than in the obligatory "e" condition, $t_1(81) = 1.86$, $p < .10$; $t_2(77) = 1.82$, $p < .10$.

[2] Data trimming procedures followed Rastle et al. (2000)Rastle et al. (2004) and McCormick et al. (2008), whereby outliers were detected by inspection of the RT distribution averaged over all conditions. The criterion for the removal of individual data points was set for each experiment individually to ensure that less than 1% of the data points were removed. The pattern of data is unchanged if a criterion of two standard deviations is used, though such a criterion removes closer to 4% of the data.

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TABLE 2
Mean RT (s) and error data (in parentheses) for Experiment 1 by participants

	Related	*Unrelated*	*Priming*
Optional “e” (adorage-ADORE)	583 (3.7%)	609 (5.4%)	26 (1.7%)
Obligatory “e” (olivant-OLIVE)	616 (7.0%)	634 (8.5%)	18 (1.5%)
Form (blunana-BLUNT)	615 (5.3%)	619 (7.9%)	4 (2.6%)

Similarly, priming effects in the obligatory “e” condition differed marginally from those in the form condition, $t_1(81) = 1.94$, $p < .10$; $t_2(77) = 1.73$, $p < .10$.

The ANOVAs on the percentage of errors made across each condition revealed a significant main effect of priming, $F_1(1, 80) = 21.43$, $p < .05$; $F_2(1, 113) = 8.83$, $p < .05$, with fewer errors being made in the primed conditions than in the control conditions. No other effects on the error data reached significance both by subjects and by items and so these data are not considered any further.

EXPERIMENT 2

Experiment 1 demonstrated that masked priming effects are observed for morphologically structured nonwords with a missing “e” at the morpheme boundary, and, critically, that these effects cannot be attributed to simple orthographic overlap between primes and targets. However, this convincing pattern of data emerged only for those nonwords constructed using stems that occur frequently in contexts in which their final “e” is deleted (e.g., adorage). Though significant priming effects also emerged for morphologically structured nonwords constructed using stems that never lose their final “e” (e.g., olivant), and though these effects were statistically indistinguishable from those obtained for the optional “e” primes, these effects could not be distinguished statistically from effects due to simple orthographic overlap. It therefore remains unclear whether robustness to orthographic change in morpho-orthographic decomposition applies only to stems that surface frequently in altered form. Experiment 2 sought to determine whether the same pattern of effects is maintained when the morphologically structured primes comprise a partial stem plus a consonant-initial suffix (e.g. adorless-ADORE). This is an unusual type of construction that applies to very few exemplars in English. We might therefore predict additional sensitivity to a missing “e” in this context (i.e., that the missing “e” might eliminate the priming effects observed in Experiment 1).

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Method

Participants. The participants were 60 previously untested volunteers from the same population as was used in Experiment 1.

Stimuli. Targets were those used in Experiment 1. Morphologically structured nonword primes in this experiment comprised the partial stem plus a frequently occurring consonant-initial suffix. Primes in the orthographic form condition were constructed in a similar manner to those in Experiment 1, with adjustments made to reflect the slightly longer length of the consonant-initial suffixes used in the morphological conditions. Primes and targets across the three conditions were matched on the same variables as in Experiment 1. Mean values for each of these variables along with statistical test data are shown in Table 1.

The construction of unrelated control primes, filler primes and targets, and nonword primes and targets was achieved in the same manner as in Experiment 1, as was the counterbalancing of items across participants. Including the experimental, filler, and nonword trials, each participant made 320 lexical decisions. Test stimuli for this experiment are presented in Appendix A.

Apparatus and procedure. The apparatus and procedural details of this experiment were identical to those in Experiment 1.

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Results

The exclusion criteria described in Experiment 1 led to the removal of three participants and four items (SLINK, TERSE, MOROSE, and TRITE). Forty-five further outlying data points over 1800 ms were removed (0.73% of correct responses). Data were analysed as in Experiment 1. Latency and error data for Experiment 2 are shown in Table 3.

TABLE 3
Mean RT (s) and error data (in parentheses) for Experiment 2 by participants

	Related	*Unrelated*	*Priming*
Optional “e”			
adorly-ADORE	569 (4.9%)	595 (3.0%)	27 (−1.9%)
Obligatory “e”			
olivment-OLIVE	603 (10.4%)	618 (11.1%)	15 (0.7%)
Form			
blunana-BLUNT	610 (7.7%)	620 (9.8%)	10 (2.1%)

The ANOVAs on the latency data revealed an interaction between condition and priming that was significant by subjects and by items, $F_1(2, 110) = 3.57$ $p < .01$; $F_2(2, 110) = 4.67$, $p < .01$. In order to investigate the source of this interaction, *t*-tests were used to establish the amount of priming within each condition. There was significant priming in the optional "e", $t_1(56) = 6.53$, $p < .001$; $t_2(39) = 5.46$, $p < .01$, and obligatory "e" morphological conditions, $t_1(56) = 2.76$, $p < .05$; $t_2(36) = 2.60$, $p < .05$, but only marginally significant priming in the nonmorphological form condition, $t_1(56) = 1.91$, $p < .10$; $t_2(38) = 1.70$, $p < .10$. Comparisons of priming effects between the conditions confirmed that the effects were larger in the optional "e" condition than in the orthographic form condition, t_1 $(56) = 2.60$, $p < .01$; $t_2(77) = 2.80$, $p < .01$, and that the effects in the optional "e" condition were marginally larger than in the obligatory "e" condition, $t_1(56) = 1.94$, $p < .10$; $t_2(75) = 2.08$, $p < .05$. Priming effects in the obligatory "e" condition did not differ significantly from those in the orthographic form condition, $t_1(56) = 0.63$, *ns*; $t_2(74) = 0.69$, *ns*.

No effects were observed on the error data that reached significance both by subjects and by items and so these data are not considered any further.

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EXPERIMENT 3

Experiments 1 and 2 showed that masked priming effects can be obtained with morphologically structured English nonwords that have a missing "e" at the morpheme boundary, that these effects are significantly greater than those observed for orthographic overlap alone, and that they are observed irrespective of the nature of the suffix used (i.e., whether it began with a vowel or consonant). However, this is the case only when the morphologically structured nonwords are constructed using stems that frequently lose their final "e" (e.g., adorage). The pattern of data is much less clear when morphologically structured nonwords consist of stems that never lose their final "e" (e.g., olivant). Though priming effects from these constructions were significant in both Experiments 1 and 2, they could not be distinguished clearly from morphological priming using optional "e" items on the one hand and simple orthographic priming on the other. It seems therefore that a definitive answer to the fourth question posed in this paper (i.e., whether robustness to orthographic alteration in morpho-orthographic decomposition is maintained when stems never surface in orthographically altered form) remains elusive. We return to this issue in the General Discussion.

Experiment 3 turns back to the priming effects observed for morphologically structured nonwords constructed using optional "e" stems (e.g., adorage, adorless). Experiment 1 and 2 already demonstrated that these

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priming effects are robust and that they can be distinguished statistically from priming effects due to simple orthographic overlap. However, even though these data are much more convincing than previous work on the question of whether morphologically structured nonwords undergo morpho-orthographic decomposition, a potential problem remains. Specifically, this comparison between morphological priming (e.g., adorage-ADORE) and form priming (e.g., blunana-BLUNT) involved different sets of targets. Though these target sets were very well matched, it is nevertheless important to establish that the effects obtained cannot be reduced to baseline differences across them (i.e., to rule out the possibility that the morphological targets were more susceptible to priming than the form targets). This issue is particularly pressing because in both experiments recognition of targets in the form condition following unrelated primes appears slower and more error prone than recognition of targets in the morphological condition, Experiment 1: 609 ms (5.4% error) versus 619 ms (7.9% error); Experiment 2: 595 ms (3.0% error) versus 620 ms (9.8% error).

Experiment 3 thus explored partial stem priming (e.g., ador-ADORE) using the targets from Experiments 1 and 2. In order to be totally confident that priming effects observed for optional "e" items cannot be reduced to simple form priming, it will be important to establish that there are no differences across these conditions in partial-stem priming.

Method

Participants. The participants were 60 previously untested volunteers from the same population as was used in Experiment 1

Stimuli. Targets for this experiment were taken from Experiment 1. Primes in this experiment consisted of the target minus the final letter (e.g., ador-ADORE). Lexical statistics for these materials are available in Table 1.

Unrelated control primes were chosen for each of the 120 target words. They were matched pairwise on length and groupwise on stem frequency and stem neighbourhood size to the related primes and consisted of monomorphemic words minus the final letter (e.g., "tria" which is the word "trial" without the final letter).

Forty pairs of totally unrelated primes and targets were added to the stimulus set in order to reduce the overall relatedness proportion to 37% as in Experiments 1 and 2. Filler primes were constructed as described for unrelated control primes from words matched to experimental primes on length and stem frequency.

One hundred and sixty nonword targets were taken from Experiment 1. Nonword primes were constructed from a group of monomorphemic words which were groupwise matched to experimental/filler primes on length and frequency.

The counterbalancing of stimuli across participants was achieved as in Experiment 1. Including the experimental, filler, and nonword trials, each participant made 320 lexical decisions. Test stimuli for this experiment are presented in Appendix B.

Apparatus and procedure. The apparatus and procedural details of this experiment were identical to those in Experiment 1.

Results

The exclusion criteria described in Experiment 1 led to the removal of two participants and one item (TRITE). Forty-seven further outlying data points over 1700 ms were removed (0.73% of the data). Data were analysed as in Experiment 1. Latency and error data for Experiment 3 are shown in Table 4.

The ANOVAs on the latency data showed a significant main effect of priming, $F_1(2, 112) = 57.32$, $p < .01$; $F_2(1, 113) = 76.79$, $p < .001$. No other effects on the latency data reached significance both by subjects and by items.

No effects were observed on the error data that reached significance both by subjects and by items.

Discussion

The critical result of Experiment 3 was that priming in the optional "e" and nonmorphological form conditions was statistically indistinguishable and numerically very similar (27 ms vs. 23 ms). This result strengthens the findings from Experiments 1 and 2 showing a reliable difference between priming in the optional "e" and nonmorphological form conditions, because

TABLE 4
Mean RT (s) and error data (in parentheses) for Experiment 3 by participants

	Related	*Unrelated*	*Priming*
Optional "e"			
ador-ADORE	550 (3.4%)	577 (3.6%)	27 (0.2%)
Obligatory "e"			
oliv-OLIVE	576 (8.9%)	591 (8.6%)	15 (−0.3%)
Form			
blun-BLUNT	572 (6.7%)	595 (8.1%)	23 (1.4%)

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it shows that targets in these two conditions had the potential to be primed to the same degree.

The results from the obligatory "e" condition were less important for this experiment. However, the finding of a 12 ms numerical difference between obligatory "e" and optional "e" conditions makes interpretation of this contrast in Experiments 1 and 2 even more difficult, because it suggests that obligatory "e" targets may have been less susceptible to priming than optional "e" targets.[3] Potential explanations for this are considered in the General Discussion.

GENERAL DISCUSSION

The focus of this series of experiments was on the process of morphological decomposition that is thought to occur during the initial stages of visual word perception. There is building evidence that this process is based on the *mere appearance* of morphological complexity, such that it occurs anytime a printed stimulus can be segmented into known morphemes (Longtin et al., 2003; Rastle et al., 2004). One important prediction of this claim about morphological decomposition is that it should arise for morphologically structured nonwords (e.g., habitness). This prediction has gained support from a recent study of masked priming (Longtin & Meunier, 2005), in which the impact of morphologically structured French nonword primes on the recognition of stem targets was examined. Results showed that such primes facilitated the recognition of stem targets, and that the magnitude of these priming effects did not differ from those yielded by semantically transparent derived words.

However, this study did not show unequivocally that the effects observed were not due to simple orthographic overlap between primes and targets. Because of this problem, and because evidence concerning morpho-orthographic decomposition for words has not always proved reliable in French (see Diependaele et al., 2005), the first aim of our research was to establish more convincingly that masked morphological priming effects could be observed when using morphologically structured nonword primes. Results from both Experiments 1 and 2 demonstrated unambiguously that at

[3] Some could argue that this 12 ms numerical difference suggests that ADORE targets are stored in an underspecified manner, whereas OLIVE targets are not (and that is why a partial-stem prime facilitates recognition of ADORE items more than it facilitates recognition of OLIVE items). In addition to the fact that this possibility is not clearly supported by Experiments 1 and 2, a further experiment investigating masked identity priming with the targets used in Experiment 3 yielded a similar numerical (but nonsignificant) difference between these conditions. This result is consistent with our suggestion that OLIVE targets may simply have been less susceptible to priming than ADORE targets.

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least some types of morphologically structured nonword primes (see later) facilitate recognition of their stem targets, and critically, that the magnitude of these priming effects is significantly larger than would be expected on the basis of simple orthographic overlap between prime and target. This finding provides important support for the notion of a morphological decomposition process that segments stimuli on the basis of their *appearance* of morphological complexity without any regard to semantic or lexical factors (e.g., Longtin & Meunier, 2005; Longtin et al., 2003; McCormick et al., 2008; Rastle & Davis, 2003; Rastle et al., 2004).

The second aim of our experiments was to investigate whether this decomposition process breaks down when morphologically structured nonword stimuli cannot be parsed perfectly into their constituents because of a missing "e" at the morpheme boundary (e.g., adorage-ADORE). McCormick et al. (2008) recently demonstrated that such orthographic alterations do not hinder the decomposition process in respect of *word* stimuli. However, because the bulk of their evidence concerned semantically transparent derived forms (in which robustness to orthographic alteration could be the result of learned lexicosemantic links between morphological relatives like "adorable" and "adore"), we felt that it was important to reexamine the issue using morphologically structured nonword stimuli. Our results showed that at least some kinds of morphologically structured nonword stimuli (those with stems that frequently lose their "e"; e.g., adore) facilitate the recognition of their stem targets more than would be expected on the basis of simple orthographic overlap despite an imperfect match to the full orthographic form of the target. This finding provides further support for the notion advanced by McCormick et al. that stems that regularly lose their final "e" may be represented in an underspecified manner (i.e., that the final "e" may be absent or marked as optional).

The third aim of these experiments was to determine whether this robustness to orthographic alteration is dependent on the nature of the suffix used to construct the morphologically structured nonwords. Orthographic alterations such as missing "e" are far more likely to occur with vowel-initial suffixes than with consonant-initial suffixes (e.g., excitable vs. excitement). Thus, it seemed possible that a vowel-initial suffix might be necessary to "licence" the recognition system's tolerance of an imperfect match between prime and target. Somewhat against our expectations, results suggested that the nature of the suffix does not matter. For the conditions in which masked morphological priming could be reliably distinguished from nonmorphological form priming (i.e., the condition in which stems frequently lose their "e"), the magnitude of morphological priming observed with vowel-initial suffixes was of a similar magnitude (26 ms) to that observed with consonant-initial suffixes (27 ms).

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Our fourth aim was to determine whether the notion of orthographic underspecification extends to stems that never occur in an orthographically altered context (e.g., to stems such as "olive" that never lose their final "e"). Thus, we examined the effect of a missing "e" on masked morphological priming of stems that frequently occur without their final "e" (e.g., adorage-ADORE) and of stems that never occur without their final "e" (e.g., olivant-OLIVE). Results concerning this fourth aim were much less straightforward. The olivant-OLIVE items yielded significant priming in Experiments 1 and 2, and the magnitude of this priming did not differ significantly from that yielded by the adorage-ADORE items. However, these priming effects (for olivant-OLIVE items) did not meet the stronger test of being reliably different from nonmorphological form priming. The results of Experiment 3 complicate matters further since they suggested (on numerical grounds at least) that the obligatory "e" targets were less susceptible to priming than were the optional "e" targets. Ultimately, therefore, we are unable to offer a definitive conclusion with respect to our fourth aim: It remains unclear whether robustness to orthographic alteration in morpho-orthographic segmentation extends to stems that never surface in altered form.

It seems worthwhile to consider potential reasons why we were unable to meet our fourth aim in this instance. One important problem concerns the selection of optional "e" versus obligatory "e" items. Stems that never lose their final "e" tend *not* to be verbs (verbs ending in "e" tend to lose their final "e" in the inflectional context of -ing) and tend to have very low family sizes. By contrast, stems that frequently lose their final "e" are often verbs and often have very high family sizes. These generalisations are backed up by analyses of our own stimuli: Whereas our optional "e" items had a mean family size of 12.9 and included 26 verbs, our obligatory "e" items had a mean family size of 4.4 and included no verbs. Stems from large morphological families tend to elicit faster response times than words from smaller families in single word lexical decision (Baayen, Feldman, & Schreuder, 2006; Martin, Bertram, Haikio, Schreuder, & Baayen, 2004; Martin et al., 2005; Pastizzo & Feldman, 2004), and it seems possible that family size might also interact with the size of morphological priming effects (Feldman & Basnight Brown, 2007).

If these variables could be matched appropriately across the optional "e" versus obligatory "e" comparison, then we might be in a better position to draw sound conclusions with respect to our fourth aim. Unfortunately, however, these are natural confounds that (at least in English) cannot be avoided in selecting these kinds of stimuli. It is possible that these confounds would not be present in another language. Alternatively, it might be possible to examine this issue through word-learning studies (e.g., Bowers, Davis, & Hanley, 2005; Gaskell & Dumay, 2003), in which participants were trained on a perfectly matched set of novel stems that varied only in whether they were encountered without their final "e" in various morphological contexts. Once these stems were learned, one could then use them to construct morphologically structured nonwords similar to our "adorage" and "olivant" items, and one could investigate whether robustness to orthographic alteration is observed in both cases. More generally, because the word-learning methodology offers a perfect means of matching stimuli on multiple dimensions, it could prove a very valuable addition to the armoury of techniques used for studying morphological processing.

Overall, this work has been successful in meeting three of our original four aims. The masked priming experiments that we report suggest unambiguously that morphologically structured nonwords are subject to a decomposition process early in visual word recognition. Further, at least with respect to those stems that surface frequently in orthographically altered form, this decomposition process appears robust to regular orthographic changes that characterize complex words (see also McCormick et al.,. 2008). Finally, despite the sophistication that this result implies, the decomposition process does not appear to be sensitive to distributional facts about the nature of suffixes that occur in the context of the missing "e". Further work is needed to determine whether robustness to orthographic alteration in morpho-orthographic segmentation also applies to stems that never surface in altered form.

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APPENDIX A
Test stimuli for Experiments 1 and 2

	Experiment 1		*Experiment 2*		
Condition	*Related*	*Unrelated*	*Related*	*Unrelated*	*Target*
Obligatory "e"					
	anklance	harsance	anklment	harsment	ANKLE
	applant	daisant	applness	daisness	APPLE
	axlion	judion	axlment	judment	AXLE
	bladable	drowable	bladment	drowment	BLADE
	blokory	chalory	blokment	chalment	BLOKE
	bluage	meeage	bluful	meeful	BLUE
	chutity	twerity	chutness	twerness	CHUTE
	dudance	gonance	dudness	gonness	DUDE
	eaglance	forsance	eaglment	frosment	EAGLE
	estatant	priesant	estatness	priesness	ESTATE
	flukion	tainion	flukness	tainness	FLUKE
	mytity	genity	genment	mytment	GENE
	grovion	flanion	grovness	flanness	GROVE
	kitity	dunity	kitment	dunment	KITE
	litrion	drafion	litrness	drafness	LITRE
	maplant	blitant	maplness	blitness	MAPLE
	meric	bomic	merhood	bomhood	MERE
	morosive	flaunive	morosless	flaunless	MOROSE
	niecant	bertant	niecness	bertness	NIECE
	noodlion	infesion	noodlment	infesment	NOODLE
	olivant	shafant	olivment	shafment	OLIVE
	ornatal	almonal	ornatful	almonful	ORNATE
	peacion	climion	peacment	climment	PEACE
	plaquable	deporable	plaqument	deporment	PLAQUE
	politate	asserate	politment	asserment	POLITE
	quitate	everate	quitlet	spealet	QUITE
	rabblant	blighant	rabblness	blighness	RABBLE
	ravinant	starcant	ravinment	starcment	RAVINE
	rubblity	intenity	rubblness	intenness	RUBBLE
	rudance	hosance	rudful	hosful	RUDE
	scribion	cobalion	scribment	cobalment	SCRIBE
	sincal	flesal	sincment	flesment	SINCE
	swedion	thonion	swedness	thonness	SWEDE
	swinable	dandable	swinness	dandness	SWINE
	tersage	drolage	tersful	drolful	TERSE
	tritage	snorage	trithood	snorhood	TRITE
	twicate	broalet	twiclet	broalet	TWICE
	unclable	guarable	unclness	guarness	UNCLE
	vasant	dunant	vasment	dunment	VASE
	venuable	flirable	venument	flirment	VENUE

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Appendix A (*Continued*)

	Experiment 1		*Experiment 2*		
Condition	*Related*	*Unrelated*	*Related*	*Unrelated*	*Target*
Optional "e"					
	adorage	clasage	adorly	clasly	ADORE
	amplous	nannous	amplhood	nannhood	AMPLE
	amusism	grinism	amusly	grinly	AMUSE
	arguism	eartism	arguness	eartness	ARGUE
	bridable	tootage	bridness	tootness	BRIDE
	carvate	hellity	carvhood	hellhood	CARVE
	crudory	waisory	crudless	waisless	CRUDE
	cyclity	ghosity	cyclness	ghosness	CYCLE
	densify	eldeify	densful	eldeful	DENSE
	elitable	shelable	elitment	shelment	ELITE
	erasify	hyenify	erashood	hyenhood	ERASE
	farcion	quarion	farcment	quarment	FARCE
	fencity	drifity	fencness	drifness	FENCE
	forcity	glasity	forcness	glasness	FORCE
	forgity	stinory	forgness	stinness	FORGE
	gamblity	wrencity	gamblment	wrencment	GAMBLE
	globory	torcory	globment	torcment	GLOBE
	guidity	trusity	guidness	trusness	GUIDE
	inanive	prisive	inanless	prisless	INANE
	jokity	lurity	jokment	lurment	JOKE
	jugglity	defecity	jugglness	defenness	JUGGLE
	metrity	trinity	metrness	trunness	METRE
	mincity	trasity	mincness	trasness	MINCE
	nervity	crafity	nervness	crafness	NERVE
	noblive	tempive	noblment	tempment	NOBLE
	noisage	drafable	noisness	drafness	NOISE
	nursity	broaity	nursness	broaness	NURSE
	obesic	scowic	obeshood	scowhood	OBESE
	pulsity	dwarity	pulsness	dwarness	PULSE
	puzzlity	rockeity	puzzlness	rockeness	PUZZLE
	ramblity	gulleity	ramblness	gulleness	RAMBLE
	saucity	yielity	saucness	yielness	SAUCE
	scenant	boarant	scenment	boarment	SCENE
	seizify	gianify	seizly	gianly	SEIZE
	sensable	fielable	sensness	fielness	SENSE
	servage	moutage	servly	moutly	SERVE
	skatity	belcity	skatness	belcness	SKATE
	smility	laugity	smilness	hoteness	SMILE
	stylity	wisity	stylness	whisness	STYLE
	toddlous	patteous	toddlment	pattement	TODDLE

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Appendix A (*Continued*)

Condition	*Experiment 1* *Related*	*Experiment 1* *Unrelated*	*Experiment 2* *Related*	*Experiment 2* *Unrelated*	*Target*
Orthographic form					
	amellan	ganllan	amelliple	gnalliple	AMEN
	angrass	twisass	angrass	twisass	ANGRY
	anorawl	gospewl	anoranble	gospenble	ANORAK
	attiff	recuff	attifust	recufust	ATTIC
	bliston	cargton	bliston	cargton	BLISS
	bliterim	psalerim	bliterim	psalerim	BLITZ
	blunana	prowana	blunana	prowana	BLUNT
	borrocot	shivecot	borrocot	shivecot	BORROW
	cannozle	butlexle	cannozle	butlexle	CANNON
	cartorim	fennerim	cartorim	fennerim	CARTON
	chilge	amenge	chilpen	amenpen	CHILL
	clirrelk	fourrelk	clirrelk	fourrelk	CLIP
	clourus	rapirus	clourind	rapirind	CLOUD
	collahin	petrohin	collahin	petrohin	COLLAR
	comzle	bawzle	comrype	bawrype	COMA
	coucel	terrel	coucrenk	terrtrenk	COUCH
	counzen	queezen	counssem	queessem	COUNT
	crumtock	spawtock	crumtock	spawtock	CRUMB
	eartock	studock	eartumnle	studumnle	EARTH
	eczemoon	fathonge	eczemoon	fathonge	ECZEMA
	exacque	shelque	exacpect	shelpect	EXACT
	flanemn	berremn	flannow	berremn	FLANK
	flinge	doonge	flinlett	doonlett	FLIP
	gright	soaght	grinque	soanque	GRIP
	harsano	thumano	harsano	thumano	HARSH
	hernch	flench	herthrom	flethrom	HERO
	moullow	swamlow	moullow	swamlow	MOULD
	narrocco	bullecco	narrolear	bullelear	NARROW
	navifund	jerifund	navifund	jerifund	NAVY
	poplabus	jargobus	poplabuss	jargobuss	POPLAR
	quiench	civinch	quienass	civinass	QUIET
	scolpse	masopse	scollple	masolple	SCOLD
	slinfle	poppfle	slintril	popptril	SLINK
	starain	wrisain	starain	wrisain	START
	tailonna	dismanna	tailonna	dismanna	TAILOR
	targenge	shadonge	targenge	shadonge	TARGET
	terringe	sofinge	terringe	soffinge	TERM
	towemph	spoomph	towebriss	spoobriss	TOWEL
	utteple	robiple	uttebute	robibute	UTTER
	voweron	penaron	voweron	penaron	VOWEL

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APPENDIX B
Test stimuli for Experiment 3

Condition	*Experiment 3*		
	Related	*Unrelated*	*Target*
Obligatory "e"			
	ankl	stee	ANKLE
	appl	fain	APPLE
	axl	moa	AXLE
	blad	logi	BLADE
	blok	drea	BLOKE
	blu	ste	BLUE
	chut	braw	CHUTE
	dud	tan	DUDE
	eagl	deca	EAGLE
	estat	screa	ESTATE
	fluk	mucu	FLUKE
	gen	pac	GENE
	grov	sobe	GROVE
	kit	pea	KITE
	litr	spra	LITRE
	mapl	vigi	MAPLE
	mer	boi	MERE
	moros	gulle	MOROSE
	niec	cora	NIECE
	noodl	garre	NOODLE
	oliv	lorr	OLIVE
	ornat	cemen	ORNATE
	peac	radi	PEACE
	plaqu	frigi	PLAQUE
	polit	mutte	POLITE
	quit	ever	QUITE
	rabbl	indig	RABBLE
	ravin	emble	RAVINE
	rubbl	thirs	RUBBLE
	rud	vai	RUDE
	scrib	minno	SCRIBE
	sinc	clas	SINCE
	swed	botc	SWEDE
	swin	caro	SWINE
	ters	exal	TERSE
	trit	alde	TRITE
	twic	suga	TWICE
	uncl	chea	UNCLE
	vas	emi	VASE
	venu	cide	VENUE
Optional "e"			
	ador	draf	ADORE
	ampl	nann	AMPLE
	amus	cree	AMUSE

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Appendix B (*Continued*)

	Experiment 3		
Condition	*Related*	*Unrelated*	*Target*
	argu	staf	ARGUE
	brid	torc	BRIDE
	carv	bras	CARVE
	crud	magi	CRUDE
	cycl	gree	CYCLE
	dens	blan	DENSE
	elit	pian	ELITE
	eras	repe	ERASE
	farc	scal	FARCE
	fenc	stor	FENCE
	forc	alon	FORCE
	forg	chal	FORGE
	gambl	tethe	GAMBLE
	glob	scar	GLOBE
	guid	elec	GUIDE
	inan	park	INANE
	jok	axi	JOKE
	juggl	maroo	JUGGLE
	metr	proo	METRE
	minc	flir	MINCE
	nerv	craf	NERVE
	nobl	trai	NOBLE
	nois	beac	NOISE
	nurs	boun	NURSE
	obes	clin	OBESE
	puls	idio	PULSE
	puzzl	absen	PUZZLE
	rambl	sonne	RAMBLE
	sauc	rugb	SAUCE
	scen	touc	SCENE
	seiz	floa	SEIZE
	sens	allo	SENSE
	serv	doub	SERVE
	skat	hois	SKATE
	smil	wron	SMILE
	styl	groi	STYLE
	toddl	bicke	TODDLE
Orthographic form			
	ame	zes	AMEN
	angr	tria	ANGRY
	anora	beagl	ANORAK
	atti	glar	ATTIC
	blis	crea	BLISS
	blit	tras	BLITZ
	blun	foye	BLUNT
	borro	chees	BORROW

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Appendix B (*Continued*)

	Experiment 3		
Condition	*Related*	*Unrelated*	*Target*
	canno	thril	CANNON
	carto	pounc	CARTON
	chil	tors	CHILL
	cli	sec	CLIP
	clou	shee	CLOUD
	colla	oxyge	COLLAR
	com	hee	COMA
	couc	knol	COUCH
	coun	shar	COUNT
	crum	larv	CRUMB
	eart	shak	EARTH
	eczem	fatho	ECZEMA
	exac	devi	EXACT
	flan	boot	FLANK
	fli	pra	FLIP
	gri	til	GRIP
	hars	stov	HARSH
	her	too	HERO
	moul	bulg	MOULD
	narro	escap	NARROW
	nav	rol	NAVY
	popla	thron	POPLAR
	quie	basi	QUIET
	scol	glaz	SCOLD
	slin	humu	SLINK
	star	part	START
	tailo	musse	TAILOR
	targe	glanc	TARGET
	ter	mil	TERM
	towe	essa	TOWEL
	utte	demo	UTTER
	vowe	luci	VOWEL

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