Psychonomic Bulletin & Review (2020) 27:379–384
https://doi.org/10.3758/s13423-019-01683-w

BRIEF REPORT

The role of phonology in processing morphologically complex words

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Abstract

This study investigated the role of phonology in the processing of morphologically complex words in a masked priming experiment. An English stem word target was preceded by either its derived form, sharing the phonological information with its stem (P+; *healer–HEAL*), or its derived form with a phonological change from the stem (P−; *health–HEAL*). Interestingly, both P+ and P− conditions showed comparable priming, suggesting that phonological information does not play a crucial role at least at early stages of morphological decomposition. This finding does not support the distributed connectionist approach of morphological processing, that maintains that morphemes are patterns of activation distributed across spelling, sound, and meaning. In fact, our results suggest that morphemes are explicitly represented as discrete units in the mental lexicon.

Keywords Morphological decomposition · Phonological information · Distributed connectionist approach

It is established that morphologically complex words, such as *cleaner*, are decomposed into their individual constituents, *clean* and *-er*, during early stages of visual word recognition. This is based on numerous studies yielding a robust masked priming effect with the morphologically complex word as the prime and its stem as the target (*cleaner–CLEAN*) (Beyersmann et al., 2016; Diependaele, Duñabeitia, Morris, & Keuleers, 2011; Diependaele, Morris, Serota, Bertrand, & Grainger, 2013; Diependaele, Sandra, & Grainger, 2005; Feldman, Kostíc, Gvozdenović, O'Connor, & del Prado Martín, 2012; Feldman, O'Connor, & del Prado Martín, 2009; McCormick, Rastle, & Davis, 2008; Rastle, Davis, & New, 2004). Many masked priming studies testing how morphologically complex words are decomposed have mainly focused on the role of semantics. Specifically, these studies have examined whether semantic opacity plays a role during early stages of morphological decomposition (Feldman et al., 2012; Feldman et al., 2009), or such decomposition relies solely on orthographic form (Rastle et al., 2004). Even though there have been many studies supporting orthographic form-based decomposition (Beyersmann et al., 2016; McCormick et al., 2008; Rastle et al., 2004), little work has been done on whether phonological changes play any role during these early stages of morphological decomposition. Thus, this study specifically tests whether phonological information is necessary in order to obtain masked morphological priming.

The classical approach to morphological processing assumes that decomposition of morphologically complex words occurs because morphemes are explicitly represented in the mental lexicon. That is, both *clean* and *-er* have mental representations such that *cleaner* is decomposed into these constituents (Marslen-Wilson, Tyler, Waksler, & Older, 1994; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; Taft & Forster, 1976). In other words, this approach assumes that there is a level of morphology, and priming from a morphologically complex word to its stem (*cleaner–CLEAN*) results from activating the shared morphemic representation. This is further evidenced by the fact that orthographic form overlap alone does not yield such priming, as in *brothel–BROTH* (e.g., Rastle et al., 2004), because *-el* is not an English morpheme. As mentioned, although there is much work done on whether this early decomposition of morphologically complex words occurs at the orthographic level (Rastle et al., 2004), semantic level (Feldman et al., 2009), or both (Diependaele et al., 2005), this classical approach has not been explicit about the role phonological information plays during the early stages of visual word recognition of morphologically complex words.

A different approach to morphological processing is maintained by the distributed connectionist approach. Under this

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framework, morphemes are patterns of activation distributed across spelling, sound, and meaning (Gonnerman, Seidenberg, & Andersen, 2007; Plaut & Gonnerman, 2000; Rueckl, 2010; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997; Seidenberg & Gonnerman, 2000). There are two main differences between the traditional approach and this distributed connectionist approach. First, the classic approach assumes that morphemes are discrete units, whereas the connectionists consider them as activation patterns that connectionist networks have developed based on inputs and outputs. Secondly, although the classic approach is not explicit in how phonological information is used during morphological processing, this approach assumes that these connectionist networks are trained to use phonological information depending on how consistent the input is. This connectionist approach assumes no localist representations, and the recognition of a complex word is the result of the activation of a pattern of connection weights. Thus, under this approach, the relationship between the derived word and its stem can be graded depending on how similar/different they are semantically, orthographically, and phonologically. Hence, the priming effect from a morphologically complex word to its stem (*acceptable–accept*) should be predictable from the degree of semantic and phonological overlap between them (Gonnerman et al., 2007). Therefore, differing from the traditional approach, this approach posits an important role for phonology in the processing of complex words, and any phonological change between the derived form and its stem would result in a smaller priming effect.

Evidence seems to be mixed as to whether phonological information is necessary when processing morphologically complex words. When both the morphologically complex word and its stem were presented visually, phonological effects are unlikely to be observed. For example, using long-term priming procedure, Napps (1989) and Fowler, Napps, and Feldman (1985) found that there were equivalent priming effects regardless of whether the complex word and its stem shared phonology (*healer–heal*) or not (*health–heal*). Similarly, Tsapkini, Kehayia, and Jarema (1999) found no difference in priming between prime–target pairs that underwent phonological change (*conclude–conclusion*) and those that did not (*doubt–doubtful*) using an unmasked priming procedure. (Note that stems preceded the complex forms in this particular study.) Similar findings were also found in Feldman and Fowler (1987) in Serbo-Croatian. Interestingly, even in an auditory task in which phonological information would seem to be important, both phonologically intact pairs (*excitement–excite*) and phonologically changed pairs (*sanity–sane*) showed no differences in their priming effects (Marslen-Wilson & Zhou, 1999). Cross-modal priming procedure, however, has yielded some phonological effects. This procedure presents primes auditorily and targets visually. Although Marslen-Wilson et al. (1994) found no phonological effects using this procedure, Tsapkini et al. (1999) found that the priming effect was larger in the phonologically transparent condition than in the phonologically opaque ones, even though they did not find such effects in the visual priming study. Using a similar cross-modal procedure, Gonnerman et al. (2007) also explored the processing of complex words. In their study, numerically graded priming effects were found between the derived form and its stem when there was no phonological change (*acceptable–accept*) and when there were phonological changes, as in consonantal changes (*absorption–absorb*), vowel changes (*criminal–crime*), and both consonant and vowel changes (*introduction–introduce*).

Based on these results, Gonnerman et al. (2007) argued that the processing of complex words is due to activation patterns through the weighing of orthographic, phonological, and semantic information, and that there are graded effects depending on phonological similarity (see also Rueckl, 2010). So, the question remains as to why differentiating phonological similarity did not affect priming of these morphologically related prime–target pairs in many other studies. One reason might be because these studies employed a task that may not have tapped into early stages of morphological processing. Indeed, some masked priming studies have indicated that phonological information might be activated during early stages of visual word recognition. Even though the effect is usually not large (Rastle & Brysbaert, 2006), there are enough studies suggesting masked phonological priming (see, e.g., Ferrand & Grainger, 1992, 1994; Grainger & Ferrand, 1994). Thus, it could be the case that phonology plays a role during early stages in morphological processing, but it is difficult to observe using experimental procedures that might only tap into later stages of such processing, such as the cross-modal task.

Therefore, the current study addresses this issue of whether phonological information is used during early stages of processing morphologically complex words by exploring the processing of English derivational words. English is a good testing ground for examining this issue because English spelling and sound system is not regular. This allows an English word (*HEAL*) to have two derived forms, with one preserving the pronunciation of the stem (*healer*) and the other involving sound change of the stem (*health*). Specifically, in this study, participants were presented with either the phonologically intact derived word (P+; *healer*) or the phonologically changed derived word (P−; *health*) as the prime and its stem (*HEAL*) as the target. If phonological information plays a role, then the P+ condition should show a larger priming effect than the P− one. If, on the other hand, phonological information does not play a crucial role in the early stages of visual word recognition, then both the P+ and the P− conditions would show similar priming effects.

Method

Participants

Thirty-two undergraduate students at the University of Texas at Arlington participated in this study for course credit. All participants reported to be native speakers of English.

Materials and design

Sixty-four English monomorphemic words were selected as word targets. The target words were partially selected from Fowler et al. (1985), Napps (1989), and English dictionaries. Each word target (*HEAL*) was preceded by one of the four different word primes: (1) P+ prime, which was a derivational form of the target word that preserves the phonology of the stem (*healer*); (2) P+ control prime, (*single*); (3) P− prime, which was a derivational form of the target word with a sound change from the stem (*health*); or (4) P− control prime (*smudge*). P− primes involved (i) a change in the vowel (n = 19; *health–HEAL*); (ii) change in the consonant (n = 9; *musician–MUSIC*); (iii) change in the vowel and the consonant (n = 14; *deception–DECEIVE*); (iv) change in the lexical stress (n = 16; *edition–EDIT*); (v) change in the lexical stress and the consonant (n = 6; *suspicion-SUSPECT*). The control primes for both P+ and P− conditions were matched in terms of word length and roughly matched for frequency to their related conditions. WordGen (Duyck, Desmet, Verbeke, & Brysbaert, 2004) was used to find these control words. Note that the mean frequencies of these primes were quite different when we used CELEX (Baayen, Piepenbrock, & Van Run, 1995) in N-Watch (Davis, 2005) to confirm whether the controls matched with their related conditions. Based on CELEX in N-Watch, the mean frequency of P+ primes was 11.53 per million, while its control was 21.92, and the mean frequency of P− primes was 15.25, and the control was 12.36. The experimental items can be found in the Appendix Table 2. Additionally, 64 nonwords were generated using the ARC Nonword Database (Rastle, Harrington, & Coltheart, 2002) to serve as the nonword targets. Four counterbalanced lists of items were created such that each target only appeared once primed by one of the four prime types.

Procedure

DMDX was used for stimuli presentation and data collection (Forster & Forster, 2003). The participants were asked to decide whether the letter string they see was a word in English and to respond as quickly and accurately as possible. For each trial, a string of hash marks (############) appeared at the center of the screen for 500 ms, followed by the prime presented in lower case for 50 ms, then by the target in uppercase for 500 ms. All stimuli were presented in 12-pt bold Courier New font. The experiment followed eight practice items.

Results

None of the participants' overall error rates exceeded 20%. Thus, data from all 32 participants were included in the analyses. By-participants and by-items ANOVAs were conducted on mean reaction times (RTs) and mean error rates (ERs) separately as dependent variables. Outliers were adjusted to 3.5 standard deviations (*SD*) above or below each participant's mean to word targets. This trimming procedure affected approximately 0.65% of the data. Subject and item analyses of variance (ANOVAs) were conducted, with prime type (P+/P−) and priming (related/control) as repeated measures, and list (for subject analysis) and item group (for item analysis) as nonrepeated measures. The mean RTs and ERs are presented in Table 1.

RT analyses showed that only priming showed a significant effect, $F_1(1, 28) = 23.71$, $p < .001$, $MSE = 24410$, $\eta_p^2 = .46$; $F_2(1, 60) = 20.30$, $p < .001$, $MSE = 54103$, $\eta_p^2 = .25$, indicating that targets were generally responded to faster when they were preceded by morphologically related primes than by morphologically unrelated ones. Prime type did not show any effect, both Fs < 1, suggesting that phonological similarity did not affect reaction times. Crucially, there was no interaction between prime type and priming, both Fs < 1, suggesting that phonology played little role in the overall priming effect. The ER analysis revealed that the main effect of priming was only significant in the subject analysis, $F_1(1, 28) = 4.31$, $p = .0472$, $MSE = .007813$, $\eta_p^2 = .13$, with related condition yielding less errors than the unrelated condition in the P− condition, but not in the item analysis, $F_2(1, 60) = 2.29$, $p = .135$. Prime type did not show any effect, both Fs < 1.16. Furthermore, there was no interaction between prime type and priming, $F_1(1, 28) = 2.36$, $p = .136$; $F_2(1, 60) = 3.13$, $p = .0821$.

Table 1 Mean reaction times (RTs) in milliseconds and error rates (ERs) for each priming condition with standard errors of the mean for repeated measures (Cousineau, 2005) in parentheses

	P+ prime		P− prime	
	RT	ER	RT	ER
Related	552 (4)	0.07 (0.01)	555 (4)	0.04 (0.01)
Unrelated	582 (3)	0.07 (0.01)	581 (6)	0.07 (0.01)
Priming	30***	0	26**	0.03*

*p < .05. **p < .01. ***p < .001

Discussion

The current study demonstrates that phonology plays little role during very early stages of processing morphologically complex words. Specifically, both the P+ and P− conditions yielded priming, with no interaction between them. When morphologically complex words are presented visually, previous studies have indicated that spelling (Rastle et al., 2004) and meaning (Feldman et al., 2009) might play a role at these early stages, but phonological information does not seem to be used. Given that phonology made little impact, at a glance, this seems to support the idea that morphemes are explicitly represented in the mental lexicon, and challenge the idea that morphemes are patterns of activation distributed over spelling, sound, and meaning.

Before proceeding to a discussion of the role phonology plays in morphological decomposition, it is important to note that our P+ primes were not only phonologically more similar to the targets than the P− primes but orthographically more similar as well. Specifically, we used the edit distance function in R (`adist`) and found that P+ primes had an average edit distance of 2.59, whereas the P− primes had that of 3.45. This, however, did not yield any boost in the priming effect of the P+ condition. That is, P+ and P− conditions behaved similarly.

In fact, it is not surprising that there were no phonological effects in our study. Previous studies that have yielded masked phonological priming have used items that were 4–6 letters long and have typically used 57–64-ms prime durations (Ferrand & Grainger, 1992, 1994; Grainger & Ferrand, 1994; Rastle & Brysbaert, 2006). That is, phonological priming can only be found with shorter words presented at longer prime durations, suggesting that phonological information kicks in only after orthographic and morphological information have already become available. This does not mean that phonology has no impact in the decomposition of morphologically complex words, it just does not play a crucial role at the very early stages of morphological processing.

Given the limited role of phonology during the early stages of morphological decomposition, how are morphemes represented? This study demonstrated that even when there is a phonological change between the derived form and its stem, as long as they are morphologically related, then there is priming. This indicates that there are discrete representations of morphemes that get activated when morphologically related forms are presented. Furthermore, given that phonological change did not make a difference, it is unlikely that morphemes are represented in a way that connectionists view them. That is, at least during the early stages of recognizing visually presented morphologically complex words, it seems as though phonology does not play a large enough role such that it would have an effect on the activation of the stem. So, the question remains as to how phonology is represented even though priming between morphologically-related word pairs seem to be obtained no matter whether there is phonological overlap or not.

Although there are quite a few studies indicating how orthographic form strongly affects early stages of morphological priming, such as *corner* priming *CORN* (see, e.g., Beyersmann et al., 2016; Rastle et al., 2004), McCormick et al. (2008) have reported that there is some flexibility in how the derived forms are segmented based on orthography. Specifically, they found priming between derived forms and their stems even when there is a missing *e* (*adorable–ADORE*), a shared *e* (*lover–LOVE*), and a duplicated consonant (*dropper–DROP*). McCormick et al. (2008) accounted for this in terms of underspecified representations, and that the orthographic features that change depending on morphological contexts might not be fully specified.

Interestingly, this was based on an argument developed in spoken word recognition, an area that would expect enhanced phonological effects. Recall that Marslen-Wilson and Zhou (1999) found that even when there was a phonological change between the derived form and its stem (*sanity–sane*), this condition yielded just as strong of a priming effect as the condition with no phonological change (*excitement–excite*). Given these results, Marslen-Wilson and Zhou (1999) argued that the phonological feature that changes between the stem and its complex form (such as the vowel in *heal* when it becomes *health*) are underspecified in the lexical representation such that whether there is a phonological change or not, the derived form can still map onto the abstract morphological representation.

Based on this, we argue that when a morphologically complex word is presented visually, the lexical processor mainly employs orthographic (Rastle et al., 2004) and (to a certain extent) semantic (Feldman et al., 2009) information to segment this complex word. The stem, then, gets mapped onto the underlying morphological representation, which leads to these morphological priming effects. Given our results, phonological information might not be one of the primary sources of information during this process. However, because many proficient readers of English are aware that *health* and *heal* are phonologically dissimilar, but still morphologically related, we assume that the underlying morphological representation involves some underspecified phonological information.

Now, could this account of underspecified phonological information also be used for the distributed connectionist approach to morphemes? Note that connectionist networks can also deal with inconsistency in the input (Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000). That is, these networks can be trained based on the consistency of inputs and outputs they are exposed to such that they learn which parts of the input is informative for generating correct output and which are not. Given this, these networks can still show morphology-like priming effects even with varying amounts of orthographic, semantic, and phonological overlap between the derived form and its stem. Thus, even when there is a phonological change between the derived form and its stem, these network systems should still be able to recognize these two words as being related. Having said that, however, the main prediction that distributed connectionists make is that there should be a graded effect depending on the similarity (Gonnerman et al., 2007; Rueckl, 2010). That is, any phonological change should lead to a smaller effect. This study, however, was not able to find such interaction.

It is possible that in visual word recognition, it is not the full triangle model that is employed during morphological processing. That is, instead of weighing the activation of orthography, phonology and semantics, these networks might be retrained such that they rely mainly on orthographic and semantic information (Rueckl, 2010; Rueckl & Raveh, 1999). If this were the case, then the distributed connectionist approach could account for the results reported in this study. Either way, some adjustments to these networks seems necessary to explain why phonology does not seem to play a role in the very early stages of morphological processing.

In conclusion, the present study reported evidence indicating that phonological information is not used during very early stages of morphological processing. We have argued that this might be because we have underspecified phonological representations for stem words that have morphologically complex forms that change phonologically such that when these complex forms are decomposed, we are still able to match the stem on its representation.

Open practices statement *None of the data or materials for the experiments reported here is available, and none of the experiments was preregistered.*

Appendix

Table 2 Materials (word targets, P+, P+ control, P–, and P– control primes) used in the experiment

WORD TARGET	P+	P+ control	P–	P– control
DEEP	deeply	review	depth	frost
HEAL	healer	single	health	reward
WISE	wisely	buckle	wisdom	church
BOMB	bomber	deploy	bombard	achieve
EDIT	editor	bleach	edition	neutral
WILD	wildly	second	wilderness	grandchild
CLEAN	cleaner	summery	cleanse	genesis
CLEAR	clearly	command	clarify	disturb
TITLE	titlist	espouse	titular	manager
LYRIC	lyrical	ceramic	lyricist	workbook
MEDIC	medical	applaud	medicine	punitive
MUSIC	musical	affable	musician	stimulus
TUTOR	tutorship	photocopy	tutorial	outwards
REPEL	repellent	cardboard	repulsive	depositor
VACATE	vacation	conjunct	vacant	vacuum
NORMAL	normally	drawback	normality	formation
IGNITE	igniter	infancy	ignition	maintain
INVADE	invader	trickle	invasion	comedian
REVISE	reviser	shelter	revision	forehead
CREATE	creative	headache	creature	tribunal
REVIVE	revival	arrival	revivify	indigent
FUTILE	futileness	discipline	futility	teaspoon
NATION	nationhood	monochrome	national	feminine
CRITIC	critical	abstract	criticize	sentiment
DECIDE	decider	brother	decisive	document
DEFEND	defendant	propriety	defensive	resentful
REDUCE	reducible	swordsman	reduction	gasometer
PARENT	parenthood	alteration	parental	secretly
FRIGID	frigidness	overburden	frigidity	ethically
INDUCE	inducement	misconduct	induction	violinist
OPPOSE	opposer	decline	opposition	ordinarily
REPEAT	repeater	dwelling	repetition	underneath
PROPEL	propeller	interests	propulsion	abrasively
REDEEM	redeemable	competitor	redemption	motiveless
DECEIVE	deceiver	position	deception	shipwreck
HOSTILE	hostilely	castigate	hostility	landscape
RECEIVE	receivable	eventually	reception	doodlebug
SUSPECT	suspective	telepathic	suspicion	overthrow
ABSTAIN	picturesque	referential	pictorial	statistic
PROCESS	abstainer	paragraph	abstinence	ingredient
DEPOSIT	processor	outskirts	procession	conversely
PRODUCE	depository	enrollment	deposition	dictionary
REGULAR	producible	apprentice	productive	motivation
SUSTAIN	regularly	gradually	regulate	openness
PROPOSE	sustainable	interrupter	sustenance	protective
DESTROY	proposal	cinnamon	proposition	insincerely
DICTATE	destroyer	classical	destruction	perspective
PREPARE	dictation	impudence	dictatorial	momentarily
DIAGNOSE	preparedness	substantive	preparation	consignment
PERSUADE	diagnosis	oblivious	diagnostic	visibility
GENERATE	persuader	pedagogic	persuasive	reversible
INDICATE	generation	compliance	generative	psychology
INNOVATE	indication	attachment	indicative	congruence
CONCEIVE	innovation	instrument	innovatory	atomically
PERCEIVE	conceivable	subordinate	conception	permission
ELECTRIC	perceivable	grandmother	perception	importance
DESCRIBE	electrical	preference	electrician	effectively
MATERIAL	describable	selectivity	description	unconcerned
IMMIGRATE	materialism	speculative	materiality	association
INTEGRATE	immigration	transparent	immigrant	applicant
RECOGNIZE	integration	attenuation	integrity	treasurer
IMPRESS	recognizable	biographical	recognition	reconstruct
INTIMIDATE	impressive	shockproof	impression	additional
	intimidation	transferable	intimidatory	physiologist

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