Journal of Memory and Language 138 (2024) 104535

Contents lists available at ScienceDirect

Journal of Memory and Language

journal homepage: www.elsevier.com/locate/jml

Affix priming with variable ING in English: Implications for unique vs. dual representation

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ARTICLE INFO

Dataset link: https://osf.io/9vure/?view_only=3375dbe797294a029547e9438bae71f7

Keywords:
Affix priming
Sociolinguistic variation
Mental lexicon
Variable ING
Canonicality advantage
Spoken word recognition

ABSTRACT

Variation in the pronunciation of spoken words constitutes one of the primary challenges to theories of Spoken Word Recognition (SWR). In this paper we examine the processing and representation of a type of variation that is connected to morphology: variation in ING, which is found in words that vary between an *-ing* and an *-in'* form. This variation, which is found in monomorphemes like *awning* in addition to affixed words, has been extensively studied, and has well-known social effects. Crucially, there is no consensus in the field as to whether the variation is morphological – involving distinct *-ing* and *-in'* morphemes – or phonological in nature, with *-in'* produced from an underlying *-ing* form. We connect the morphological and phonological analyses from the sociolinguistic literature to what have been called *dual representation* and *unique representation* in the SWR literature. We report the results of a series of experiments that use an auditory priming paradigm to explore the competing predictions of the dual and unique representation approaches. Priming provides insight into what types of representations are shared between the variants, which in turn informs the theoretical opposition at the center of the discussion about the locus of ING's variation. The first of these experiments reveals priming both within and across ING variants, with significantly more priming found when both variants are *-in'*. Follow-up experiments manipulating the distance between prime and target, as well as introducing monomorphemes like *awning*, provide evidence that we interpret as favoring the unique representation view, with the *-ing/-in'* alternation being phonological in nature. Alternative explanations are explored as well, with an eye towards the directions that future work on variation might take.

Introduction

Listeners face a number of serious challenges in recognizing spoken words. One of these challenges is variation in the surface pronunciation of words. Lahiri and Marslen-Wilson, for example, identify variation as "the fundamental problem faced by a theory of the recognition lexicon" (1991:247). While a basic manifestation of the variation problem involves the mapping between discrete linguistic units (such as phonemes or word forms) and the continuous acoustic signal, the issues are not limited to the inherent continuity of articulatory gestures or to inter-speaker physiological differences. A wide range of phonetic and phonological processes, many of which are sensitive to social and stylistic context, can cause the surface form of a word to differ both across different speakers and across different instances of the same word even from the same speaker (Bürki, 2018). While there is an active literature investigating the impact of variation on spoken word recognition (SWR), the field is far from having reached a consensus on how surface form variability is processed online and linked to lexical representations (Magnuson & Crinnion, 2022; Purse et al., 2022).

In this paper we investigate a domain where questions about variation have so far received little attention: morphologically complex words. Previous work on variation in SWR has focused primarily on variable phenomena that are phonological or phonetic in nature; for example, selection of a target from along a gradient phonetic dimension (*e.g.*, VOT duration, Andruski et al. 1994), variation between discrete non-contrastive options (*e.g.*, coronal stop flapping, McLennan and Luce 2005, McLennan et al. 2003), the substitution, deletion, or insertion of contrastive phonemes (*e.g.*, /t/-deletion, Janse and Newman 2013; nasal place assimilation, Gaskell and Marslen-Wilson 1996), and more complex combinations of reduction processes (Ernestus et al., 2002). While some of this research has incidentally included morphologically-complex stimulus items, there has been little work specifically targeting variability in the surface form of affixes, which is our focus here. The question of how complex words and their component morphemes are mentally represented and accessed by listeners is an active debate in its own right (see Embick et al. (2021), Zwitserlood (2018) and Creemers

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https://doi.org/10.1016/j.jml.2024.104535
Received 1 March 2023; Received in revised form 4 May 2024; Accepted 7 May 2024
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(2023) for recent overviews). While there is disagreement about many of the details of morphological representation in the field, we draw from this line of work the idea that it cannot be taken for granted that the linguistic units or operations involved in affix variation are identical to those in stems or monomorphemic words. A recent affix priming study by Goodwin Davies and Embick (2020) points to several challenges to investigating the processing of affixes, with an eye towards priming in particular. This paper points out that affixes have extremely high frequency, that they are functional (*i.e.* purely grammatical), not lexical, that they are often prosodically weak and of short duration, and that they are often homophonous with other functional morphemes. At the very least, the lesson to draw from these observations is that variation in affixes may involve different kinds of linguistic units or operations from what is found with lexical words, differences that could be detectable in how affixes are processed.

The particular type of complex word that we examine in the work reported here is regular verbs with an ⟨-ing⟩ suffix, which display a probabilistic alternation between word-final /ŋ/ and /n/ (*working/workin'*) in American English. While this alternation, which we will refer to as "variable ING", occurs most commonly in the ⟨-ing⟩ suffix, it also appears in other word types when /ŋ/ comes after an unstressed /ɪ/ (cp. *something/somethin', awning/awnin'* etc.). Although variable ING is one of the best-studied examples of sociolinguistic variation (Campbell-Kibler, 2006, 2007, 2008, 2009; Fischer, 1958; Forrest, 2015, 2017; Hazen, 2008; Houston, 1985; Labov, 1989, 2001; Labov et al., 2011; Meyerhoff & Schleef, 2012; Tagliamonte, 2004; Tamminga, 2016, 2017; Vaughn, 2022; Vaughn & Kendall, 2018; Wald & Shopen, 1985), the sociolinguistics literature is in disagreement as to whether the alternation arises via competition between stored morphological elements, or alternatively does not arise until later in the phonology. We suggest that these competing accounts, which we outline below, implicate representational questions that overlap with those asked in the experimental study of variation in the mental lexicon, even though they are framed in different terms. This suggestion leads us to adopt primed lexical decision, one of the experimental methods that informs theories of SWR, to explore the representation of variable ING with dual goals: to directly investigate variation in suffix forms, and to bring psycholinguistic evidence to bear on a specific unresolved question from the study of variation in sociolinguistics.

Variable ING in the sociolinguistics literature

A starting point for an experimental examination of variable ING is the vast background literature on how this feature is used in everyday conversational speech. Perhaps the most intuitive observation about variable ING is that the alternation between *-ing* and *-in'* is heavily laden with social associations. The use of the more informal *-in'* variant exhibits dramatic class stratification and robust style-shifting, exerts a strong influence on listener judgments about speakers, elicits metalinguistic commentary, and has its own well-recognized orthographic representation (Campbell-Kibler 2006, Hazen 2008, Labov et al. 2006, *inter alia*).

While the sociostylistic factors shaping the use of variable ING are powerful, they are not our primary focus here. Rather, we are interested in the linguistic representation of variable ING, and the relationship between the *-ing* and *-in'* variants in particular. It is well established that the variant use rates are sensitive to the morphological properties of the words they appear in. Attachment of the ⟨-ing⟩ suffix to a verbal stem to form a progressive participle, such as *Maria is reading an article*, is consistently found to be the grammatical context in which *-in'* is chosen over *-ing* at the highest rates (Forrest 2015, Hazen 2008, Labov 2001, *inter alia*). However, variation between *-ing* and *-in'* is also found in a range of other morphological/grammatical contexts, including gerunds (*e.g. Maria's teaching of the class convinced people that she should be promoted*), monomorphemic nouns (*e.g. awning*), and the words *something* and *nothing* (see *e.g.*, Houston 1985 for a more fine-grained breakdown of ING contexts). Loosely speaking, the more verb-like ING words are more likely to be pronounced with *-in'*, with increasingly high rates of *-ing* use along a general cline of noun-like-ness (Labov, 2001). As shown in Vaughn and Kendall (2018), listener expectations reflect these quantitative patterns quite precisely, suggesting that listeners have detailed knowledge of the morphological sensitivity of ING variation in production, even though that knowledge might not appear to be immediately useful for word recognition.

The strong sensitivity of variable ING to differences in morphological structure is a contributing factor to a long-running debate about what we will refer to as the *locus of variation*. The locus of variation refers to the type of linguistic units (words, affixes, phonemes, etc.) that are actually alternating when we observe surface variation. As noted at the end of the prior section, the unresolved question in sociolinguistic analyses of ING is whether the variation arises in the phonology or the morphology.

A phonological account of variable ING holds that the variation between *-ing* and *-in'* involves an alternation between two nasal consonants that differ in place of articulation. Houston, for example, writes, "The variation therefore cannot be described solely in terms of a suffix, but as a more general variation in English affecting final nasals" (1985:23). On the most familiar phonological analysis, the competing *-in'* form is derived phonologically by a rule having some probability of changing the nasal place of articulation in any case where the relevant phonological context (/ŋ/ following an unstressed /ɪ/) is present Houston (1985), Labov (2001). An appealing property of the phonological account is that all of the linguistic contexts in which ING variation is attested can be unified under a single analysis, even though the exact rates at which the variants are used is sensitive to the morphological structure of the word.

A morphological account of variable ING, on the other hand, says that the variation arises because there are two separately-stored phonological forms – allomorphs – of the ⟨-ing⟩ suffix; Labov et al., for example, say that "the variation appears to take place at the morphological level, selecting one of two allomorphs: /ɪŋ/ or /ɪn/" (2011:434) (see also Hazen 2008, Tagliamonte 2004, Tamminga 2016). On this view, the *-ing* and *-in'* variants are different *morphological* objects that are associated with the same syntax and semantics; they (of course) differ phonologically as well. A consequence of the morphological account of variable ING, though, is that it does not unify the variation seen in morphologically complex words like *thinking* with that exhibited by monomorphemic words like *awning*. Because the latter do not contain an ⟨-ing⟩ suffix, the *-ing/-in'* variation that is found in them must be distinct from the variation in *thinking*. One possibility is that each monomorphemic word (of which there are few) has two separate pronunciations stored in the lexicon, similar to how many English speakers allow both /ikənɑmɪks/ or /ɛkənɑmɪks/ for *economics* even though there is no general alternation between /i/ and /ɛ/ in English.

These distinctions are not without consequence for sociolinguistic theory. For example, theories of sociolinguistic variation sometimes claim that variation arising from different levels of the grammar might be more or less common, more or less stable, or more or less available for social evaluation (Hinskens, 1998; Labov, 1993; Levon & Buchstaller, 2015; Meyerhoff & Walker, 2013). The ability to correctly identify loci of variation is of course crucial for the empirical evaluation of such theories; the line of work we pursue here will demonstrate how experimental methods can address these kinds of questions.

Variable ING in SWR

We aim to show how the locus of variation question that we have just outlined for variable ING can be productively connected with psycholinguistic questions about how variation is linked to representations in the mental lexicon. One very general theoretical question that has been raised in the literature on variation in SWR is whether variant forms are stored in the lexicon, or whether they arise outside of the lexicon and connect in some other way to the process of word recognition.

One prominent view is that only the canonical form of words is represented in the lexicon. Research on how both subphonemic and phonological variation impact spoken word recognition has in many cases produced evidence for processing delays triggered by deviations away from the word's "canonical" form (Connine et al., 2008; Ernestus et al., 2002; Kuijpers et al., 1996; Matter, 1989; Racine & Grosjean, 2000, 2005; Ranbom & Connine, 2007; Snoeren et al., 2008; Streeter & Nigro, 1979). This evidence for what has come to be called the *canonicality advantage* is typically interpreted as showing that a variant form produces a representational mismatch with a single abstract form stored in the mental lexicon, thereby impeding lexical access. Another type of effect that has been interpreted for the canonicality advantage hypothesis comes from priming; in particular, results suggesting that noncanonical forms make less effective primes to subsequent targets than their canonical counterparts do (Andruski et al., 1994; LoCasto & Connine, 2002; Utman et al., 2000). In another case, Sumner and Samuel (2009) find that a canonicality advantage in priming may became apparent with some distance between primes and targets even when the variants appear to produce equivalent priming initially, leading the authors to suggest that non-canonical variants "can be used in word recognition, but only the canonical form seems to be stored for later use" (2009:499).

However, the evidence for these canonicality advantage effects is far from unequivocal. A number of other word recognition experiments similar to those cited above have failed to find a canonicality advantage (Deelman & Connine, 2001; Gaskell & Marslen-Wilson, 1996; McLennan & Luce, 2005; McLennan et al., 2003; Pitt et al., 2011; Ranbom & Connine, 2007; Sumner, 2013; Sumner & Samuel, 2005); in turn, these results have been taken as evidence for models of lexical representation that deviate from the assumption that every lexical item has a single stored phonological representation. A number of alternatives are available to the unique-representation view. Lexical items could have multiple stored representations with independent phonological forms for distinct variants (*e.g.*, Bürki & Frauenfelder, 2012; Ranbom & Connine, 2007), a possibility Samuel and Larraza (2015) refer to as *dual lexical representation.* Another proposal addressing this issue holds that a range of variant forms could be encoded episodically in an exemplar-based lexicon (*e.g.*, Sumner et al., 2014).

The proposal that multiple variant forms may be directly stored in the lexicon becomes more complicated when we consider how *morphologically complex* words with varying pronunciations might be represented or recognized. This is because the more basic question of how morphologically complex words are stored in the mental lexicon is itself contentious. Broadly speaking, theories of morphology fall between two extremes: *whole-word storage* models, which posit that putatively complex words are actually stored in the lexicon as monomorphemic wholes (Butterworth, 1983; Norris & McQueen, 2008), and *full decomposition* models, which posit that words can consist of more than one independently-stored morpheme (Marantz, 2013; Taft, 2004).[1] Combining these different models with the moving parts afforded by existing theories of variation in SWR provides a somewhat larger space of possible analyses for variable ING than just "phonological" or "morphological".

First, we observe that dual lexical representation for a complex variable ING word like *thinking* could involve dual representations of an independently-represented suffix (under the assumptions of a full decomposition model), or dual representations of the whole word (under the assumptions of a whole-word storage model). These possibilities produce quite different stored forms for the variants. Fig. 1 illustrates: facets A and B show how dual lexical representation of variants for morphologically complex words would be implemented under different assumptions about morphology in the lexicon. Facet C shows a monomorphemic word, where – unlike with the complex word representations – there are two stored forms but no representation of ⟨prog(ressive)⟩.

In greater detail, the main points to focus on in the three facets in Fig. 1 are as follows.

Dual representation + decomposition. In our view, the analysis sketched in facet A of Fig. 1 can be connected directly with what we above referred to as *morphological* analyses for the locus of variable ING. Specifically, the competing surface forms of the progressive suffix represent variation in a morphological element – the affix ⟨-ing⟩ – that is not present in monomorphemic words like *awning*. Viewed in this way, ING variation in complex words is a type of *allomorphy*: by definition, a situation in which the same syntactic and semantic properties are associated with different affix forms. Allomorphy is found both in inflection (cp. participles like *eat-**en*** versus play-***ed***) and in derivation (*e.g.*, occupational nouns like *bak-**er*** versus *art-**ist***). While allomorphy is traditionally thought of as involving obligatory differences (*e.g., baker* does not vary with **bak-**ist***), the situation in the leftmost panel of Fig. 1 is *variable* allomorphy. Prior work on morphology has revealed a number of instances in which variation involves inflected forms. For example, many varieties of English allow past tense "doublets", as seen in the variation between *dreamt* and *dreamed*, or *dived* and *dove* (see *e.g.*, Kroch 1994).

Dual representation + whole word storage. When we combine dual lexical representation of variation with a whole-word storage model, we get the possibility in facet B of Fig. 1, with two distinct stored whole word forms for a single lexical item. On this analysis, the only representation shared between a form like *thinkin'* and a form like *workin'* is the final rhyme /ɪn/, meaning its form is related to *jumpin'* in the same way it is to a word like *dolphin* which has the same final rhyme, but (crucially) not as the output of variable ING. Variable ING words with different variants have no form overlap at all on this analysis, so a form like *thinkin'* has only the meaning of ⟨progressive⟩ in common with a form like *jumping*. While this does not connect precisely with the different loci of variation we have discussed so far for variable ING, an episodic implementation of the same basic idea is also possible, with each whole word form represented by many traces of *e.g.* [θɪŋkɪŋ] and [θɪŋkɪn]. Episodic analyses of variable ING are also found in the sociolinguistics literature (*e.g.*, Forrest 2017).

Dual representation + monomorpheme. Facet C of Fig. 1 shows dual representation of variation for a monomorphemic word like *awning*. If we compare facet A to facet C, we can see that on the assumptions of decomposition, a monomorpheme like *awning* has little in common with complex word ING representations: it only shares a final rhyme with same-variant forms of complex words like *thinking*, and has no representational overlap with different-variant complex forms like *thinkin'*. If we compare facet B to facet C, we can see the representations are very similar: if complex words are stored as wholes, then they have the same relationship to dual representation of variation as monomorphemes do, in that the lexicon contains two distinct phonological strings that could map to the whole word's meaning — one string ending in /ŋ/ and one string ending in /n/. However, even though the structures are parallel, it does not mean the variant forms have overlapping representations; because the alternants are word-sized strings, the only representation that is shared across word types (or, indeed, different words *within* a category) is again the rhyme for same-variant forms.

The morphological/dual representation approach in Fig. 1 contrasts directly with the view in Fig. 2, which summarizes a phonological/unique representation alternative to it. According to this type of

[1] Various hybrid approaches, positing different combinations of storage and decomposition, fall between the whole-word storage and full decomposition extremes; see Zwitserlood (2018) for discussion.

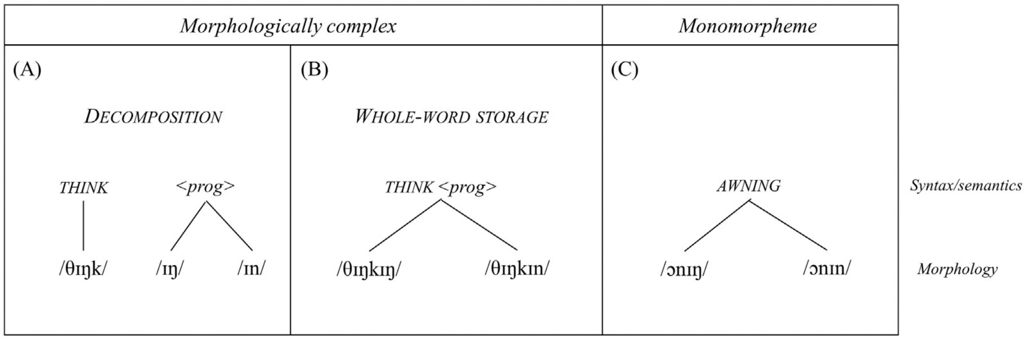

Fig. 1. Different models of morphology produce different variant representations if variation involves dual lexical representation.

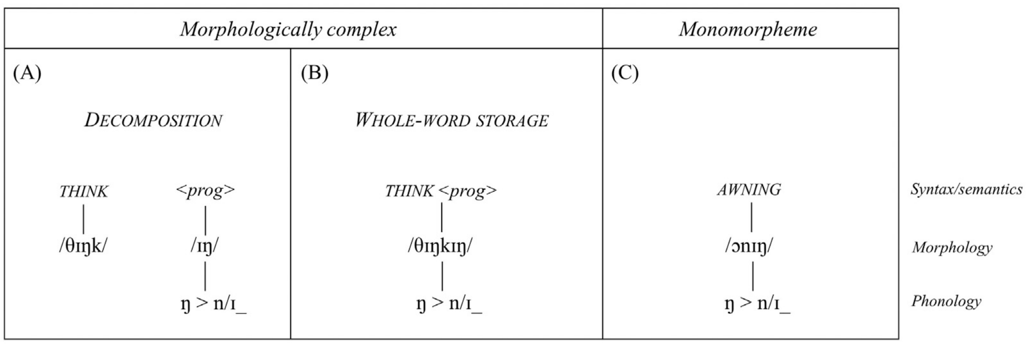

Fig. 2. Phonological account of variable ING has single locus of variation regardless of morphological complexity.

analysis, the canonical *-ing* form is the only one stored in the lexicon, for both monomorphemic and complex words: all three facets of Fig. 2 show a morpheme with the form /ɪŋ/. That is, in complex words the affix ⟨ing⟩ has the form /ɪŋ/ (decompositional view, facet A), or *thinking* is represented in memory as a progressive form of *think* that ends in /ɪŋ/ (facet B); monomorphemes like *awning* are represented in memory with the /ɪŋ/ form as well (facet C). Although the word forms here have different representations, it can now be seen that the source of ING variation is the same across all three facets of Fig. 2: the surface variation between *-ing* and *-in'* is the product of a phonological alternation that probabilistically produces the latter variant.

In summary, our discussion above considers two different ways of encoding variation: the dual representation approach, which situates the variation in the morphology; and the unique representation approach, which puts it in the phonology. When these possibilities are crossed with alternate views of morphological representation – decompositional versus storage-based – we derive a number of different predictions about how ING's variant forms in different types of words are related to each other. These predictions form the basis of the sequence of experiments that we undertake here, as the next section will lay out.

The current study

While the literature on variation in SWR and the literature on morphology in the mental lexicon have developed quite separately, they have in common a prominent role for **priming** methods as a source of evidence. In priming studies, shared representation(s) between prime and target words induce a detectable effect on the processing of the latter; this is typically manifested as facilitation in the reaction time to recognize the target as a word. Evidence of priming facilitation can thus serve as empirical support for hypotheses that potentially-related forms in fact share some aspect of their mental representation.

An important line of evidence in the literature on morphology in the mental lexicon comes from *morphological priming* paradigms.[2] The type of morphological priming paradigm that is directly relevant to the current study is *affix priming*, which attempts to detect an affix shared between prime and target. For example, the affix ⟨-er⟩ has been reported to induce facilitation in words like *teacher* primed by *baker* (in contrast to *e.g. baking* → *teacher*), in both the visual and auditory modalities (Duñabeitia et al., 2008; Giraudo & Grainger, 2003; Marslen-Wilson et al., 1996). Most theories of morphology assume a distinction between derivational morphology (*e.g.*, the "category-changing" suffix *-ment* in *treat-ment*) and inflectional morphology (like the past tense suffix in *play-ed*). The inflectional/derivational distinction is complex with ⟨ing⟩, since (as we noted above) it appears in more than one grammatical context, and some are arguably inflectional (*e.g.* the progressive). While most affix priming studies focus on derivational affixes, recent work from Goodwin Davies and Embick (2020) has also produced evidence for inflectional affix priming using the English plural suffix (*e.g. crimes* priming *trees*) (see also Emmorey, 1989; Reid & Marslen-Wilson, 2000; Smolìk, 2010; VanWagenen & Pertsova, 2014). We therefore expect to find priming with ⟨-ing⟩, even if it is potentially more complicated than morphemes that have been studied in prior work.

Priming studies of variation in SWR commonly use *repetition priming* to investigate the recognition process and memory encoding of the form of varying pronunciations. However, we are not aware of any studies of variation in SWR that use affix priming to investigate affixes with variable pronunciations. We use affix priming to isolate relatedness at the level of the ⟨-ing⟩ suffix, eliminating facilitation from stem overlap and thus learning whether the ⟨-ing⟩ suffix, whether produced as *-ing*

[2] Note that the majority of morphological priming research has been done with orthographically-presented stimuli. Since written representations do not encode variability in pronunciation, the applicability of prior work on affix priming to our auditory approach cannot be taken for granted.

or *-in'*, is a linguistic element that can be primed just as stems and derivational suffixes can. Asking whether we can detect priming across the variants takes this one step further by eliminating the phonological overlap between repetitions of the same variant. If *thinkin'* primes *jumping*, it suggests that the two variants of ING have some representation in common, despite the fact that the words have two different stems *and* two different surface forms of the suffix (White, 2021).

We thus conducted three continuous auditory primed lexical decision experiments to advance our understanding of how variable ING is represented and processed. Across these experiments, we employ the two variant forms as both primes and targets, allowing us to ask how both *-ing*- and *-in'*-containing primes influence the recognition of both *-ing* and *-in'*-containing targets compared to an unrelated baseline. Experiment 1 asks whether suffixed *-ing* and *-in'* forms share some common representation. We use affix priming to address this question: each critical prime–target pair consists of two ⟨-ing⟩-suffixed verbs with different verb stems. Because the verb stems are always unrelated, the prime/target overlap is isolated to the ING; thus any facilitation effects that we observe must reflect aspects of shared representation specific to the suffix. Experiment 2 replicates Experiment 1, while also introducing a condition with an additional filler trial between prime and target. The aim of this experiment is to assess whether the priming effects we observe in Experiment 1 endure across time and intervening linguistic material. Experiment 3 then introduces primes that do *not* contain the ⟨-ing⟩ suffix, but which *do* exhibit variable ING (*e.g. awning/awnin'*). This experiment allows us to investigate whether there is priming with variant forms that is independent of the ING suffix. Because the precise motivations for Experiments 2 and 3 arise from the results of Experiment 1, we provide the detailed motivations for them as they are introduced in subsequent sections of the paper.

Experiment 1

Experiment 1 is a continuous lexical decision experiment that seeks to detect facilitation produced by affixes with shared properties: critical primes and targets are always both ⟨-ing⟩-suffixed regular verbs, but never share verb stems. Three prime conditions (*-ing*, *-in'*, and unrelated control) are crossed with two target conditions (*-ing* and *-in'*) within subjects. For same-variant prime–target pairs (*-ing/-ing* and *-in'/-in'*), any observed facilitation could in principle reflect a phonological, morphological, and/or semantic relationship between prime and target, just as in any other case of affix priming. However, the cross-variant pairs (*-ing/-in'* and *-in'/-ing*) differ in the surface phonology of the affix, which could in principle disrupt affix priming if it relies on phonological overlap. If there is facilitation in cross-variant pairs, then, it would rule out the surface phonological overlap as the (sole) driver of the priming effect, and suggest that the variants are related in terms of another kind of representation (morphological or semantic).

Experiment 1 also allows us to ask whether the two forms of the ⟨-ing⟩ suffix are recognized asymmetrically or equivalently. Because the design uses both variants in both primes and targets, we are able to look for potential asymmetries in a wider range of respects than studies in which it is only the prime items that contain different variants. Recognition equivalence, in the sense of Sumner et al. (2014), would show up as equal magnitudes of facilitation in both same-variant and cross-variant pairs. Possible asymmetries, on the other hand, could manifest themselves in more than one way. Perhaps the clearest prediction is that same-variant prime–target pairs should elicit stronger priming than different-variant pairs, simply because similarity enhances priming. Another prediction, which derives from theories positing a canonicality advantage, is that the *-in'* variant might elicit weaker priming than the *-ing* variant. More generally, though, regardless of whether or not these particular predictions are supported, there is a basic question about symmetry: if there is both cross-variant facilitation *and* some form of asymmetry, it would indicate that the surface form of variants in suffixes can have a detectable influence on SWR.

Method and analysis

Participants

The participants for Experiment 1 were 67 native North American English speakers studying at the University of Pennsylvania. Participants with an overall accuracy rate (*i.e.* rate of correctly identifying items as real or nonwords) of lower than 80% were excluded from the dataset resulting in an exclusion of 10 participants such that 57 participants' data is analysed. All were recruited through the university's Psychology subject pool, and were awarded course credit for their participation.

Power calculations

To estimate the number of participants needed to have adequate statistical power to detect the effects of interest, we used data from a preliminary version of the experiment with similar experimental conditions to conduct a simulated power curve analysis in R. The experimental data used as the basis for the simulations came from 113 participants and 60 target items. Using the `mixedpower` package (Kumle et al., 2021), we simulated new data containing effects of the observed sizes from the pilot with increasing numbers of participants. We focused on two effects of interest: the presence of a non-zero priming effect with related primes ($\beta = 0.015$, $t = 4.7$) and the difference between *-ing* and *-in'* primes to *-in'* targets ($\beta = 0.014$, $t = 8.3$). With the effect sizes observed in the preliminary data, we determined that we would detect the difference between variants with a power of 80% between 20 and 30 participants, at which point the power to detect the main effect of affix priming is over 99%. We redid the same analysis with the effects of interest arbitrarily specified to be 70% of the observed preliminary coefficients. With this artificially-shrunken effect size, we achieve 80% power to detect the difference between the variants around 50 participants, with the power to detect any significant affix priming still being over 99% at that point. We therefore adopt 50 as a conservative lower bound on the target number of participants to recruit per experiment. Readers interested in the simulation models used by this package should consult Kumle et al. (2021) for details and helpful tutorials.

Materials and design

The critical stimuli in this experiment consist of 60 prime–target pairs. All primes and targets are disyllabic. The targets consist of 60 progressive verbs. In Experiment 1, half of the targets have a word-final *-ing* (*e.g. thinking*), and half a word-final *-in'* (*e.g. thinkin'*) (counterbalanced in a Latin square design). As discussed above, the primes are either progressive verbs with an *-ing* (*e.g. jumping*), progressive verbs with an *-in'* (*e.g. jumpin'*), or an unrelated disyllabic simplex verb (*e.g. jiggle*), resulting in a 3 × 2 design. These control primes serve as the phonologically, morphologically, and semantically unrelated baseline. None of the progressive prime–target pairs have phonological or semantic overlap in their stems. Prime–target pairs are matched for stem frequency to avoid pairs with a high frequency prime but low frequency target or vice versa. Whole-word frequency for primes and targets was extracted from the SUBTLEX-US corpus (Brysbaert & New, 2009) and was included as a predictor in the regression model.

A total of 198 filler pairs (a mix of real words and non-words) were included to serve a number of purposes. First, they ensure that 50% of the trials in the experiment are non-words. Second, they distract away from the critical variable ING in two ways: by ensuring that only 23% of the pairs are critical items, and by including other kinds of informal pronunciations of complex words (*e.g. basement* pronounced with a word-final glottal stop). Third, they include forms containing the surface strings of the ING variants in nonwords (*e.g. runnink* or *watchint*) so that hearing *verb*-/ɪn/ or *verb*-/ɪŋ/ is not predictive of wordhood status. Finally, they include disyllabic non-words with late disambiguation points (*e.g. rabbisk*) to force participants to listen to the end of each word before responding.

Stimuli recording and experimental apparatus

We are using a fully auditory primed lexical decision design. All stimuli were therefore recorded by an adult white male native speaker of North American English from rural Massachussetts/New Jersey. They were recorded in a sound-attenuated booth using a Blue Snowball iCE microphone. Sound files were segmented using Praat (Boersma, 2001), and normalized to equal amplitude across stimuli. No splicing was used in the creation of the stimuli, following McGowan and Sumner (2014), who suggested that splicing of a noncanonical variant into a canonical wordframe creates a contextual mismatch between the variant and wordframe.

The task was implemented using the PennController for IbexFarm, a platform for running online experiments (Zehr & Schwarz, 2018). Participants were recruited from the University of Pennsylvania subject pool for Experiment 1, Experiment 2a, and Experiment 2b, and from Prolific (www.prolific.com) for Experiment 3a and Experiment 3b.[3] The participants completed the experiment on their personal computers using headphones.

Procedure

After going through the process of informed consent, participants were told that they would hear real and nonsense words of spoken American English, and that they would have to determine whether what they heard was a real word or not. This was further elaborated on by informing participants that some of the words they would hear may be pronounced in a casual way, but that casually pronounced words are still real words of spoken American English. Participants were presented with audio examples of words pronounced with an *-in'* and words pronounced with a word-final glottaled /t/. This elaboration was motivated by pilot work that showed that with no instruction on the acceptability of casual pronunciations, participants only classified casually pronounced words as real words 60% of the time. Finally, before the start of the experiment participants completed 40 practice trials, including ING and *-ment* words pronounced in both formal and casual ways, and were given written feedback on each practice trial (*e.g. Correct, because you can say "She was callin' her mother".* or *Incorrect, because you can say "The basemen' flooded in the storm".*).

The task was a continuous auditory primed lexical decision task. Participants responded 'Word' and 'Nonword' by pressing buttons on their keyboard using their index fingers on two hands. The experiment consisted of six lists, with the three prime types matched with each of the two target types in a Latin square design, which meant that each participant saw each target only once. A random inter-stimulus interval (ISI) between 400 and 600 ms was used to avoid rhythmic responding, measuring from the end of the prime sound file or the participant's response to the prime (whichever was later) to the onset of the target. The stimuli were pseudo-randomized into three blocks to ensure consistency across the blocks, with randomized stimulus presentation within each of the blocks. After each block, participants had the option to take a break before continuing the experiment. There were a minimum of two fillers between each critical prime–target pair. In total, the experiment took participants around 25 min to complete.

Modelling

The dependent variable of interest is target reaction time (RT; measured in milliseconds from the onset of the prime or target sound file). Only trials in which the participant correctly identified both the prime and target were used for the analysis. Our instructions to participants regarding casual forms counting as words successfully increased participants' word endorsement rates for *-in'* words, yet their accuracy (79%) was still lower than the rates for *-ing* (95%) and unrelated (92%) words. We expect that these rates reflect participants' expectation violation in hearing casual forms in isolation (see also Sumner 2013). However, participants did accept the *-in'* forms the majority of the time, and the analyses we discuss here focus on those cases.

We combined minimal a priori data trimming with post-fitting model criticism, as recommended by Baayen and Milin (2010): All primes and targets with RTs shorter than 200 ms and longer than 2000 ms were excluded (1 short outlier, 86 long outliers) leaving 3019 observations.

The remaining log-transformed RTs were then analysed using linear mixed-effects models, using the `lme4` package (version 1.1-29) (Bates et al., 2015) in the R environment (R Core Team, 2021). The fixed effects in the model are the critical predictors of PRIME TYPE (Unrelated/-*ing*/-*in'*), TARGET TYPE (-*ing*/-*in'*), and their interaction, as well as the control predictors of TRIAL NUMBER, LOG PRIME FREQUENCY, LOG TARGET FREQUENCY, and LOG PRIME RT. The categorical predictors (PRIME TYPE and TARGET TYPE) were Helmert coded such that for PRIME TYPE the first contrast tests the difference between *-ing*-primed and *-in'*-primed RTs and the second contrast tests the difference between unprimed and primed RTs (whereby primed RTs here refers to the average of *-ing*-primed and *-in'*-primed RTs). For TARGET TYPE the contrast tests the difference between the *-ing* and *-in'* targets. The numeric predictors (TRIAL NUMBER, LOG PRIME FREQUENCY, LOG TARGET FREQUENCY, and LOG PRIME RT) were all centered and scaled (*i.e.*, z-scored). A truly maximal random effects structure was too complex to successfully fit to the data, so we focused on assessing the random effects that we judged to be most theoretically important: the target verb stems as a grouping factor, and individual differences both overall and in the effect of the critical conditions. We fit a model with a random intercept for verb stem and random slopes for PRIME TYPE and TARGET TYPE by participant (without estimating intercept/slope correlations). This model had a singular fit arising from zero variances for the PRIME TYPE-by-participant slopes. We removed those slopes and refit the model with only a random intercept for verb stem and random slopes for TARGET TYPE by participant (again uncorrelated with the intercepts). We then used model comparison to ask whether the TARGET TYPE-by-participant slopes significantly improved the model compared to a model without those slopes, which it turned out they did not. The final model thus contains only the target verb and participant random intercepts.

Again following Baayen and Milin (2010), model criticism was then performed in order to identify any remaining overly influential outliers. Data points with absolute standardized residuals greater than 2.5 standard deviations were removed from the data set (71 data points), after which the model was refitted. The below results are those of the final post-criticism models. P-values were obtained using the Satterthwaite method from the `lmerTest` package (version 3.1-3) (Kuznetsova et al., 2016) and considered significant at p<0.05 (for the full model output see Appendix C). Post-hoc critical comparisons between the levels of the critical predictors were performed using the `emmeans` package (version 1.7.0) (Lenth, 2022), adjusting the p-values using the Tukey method to account for multiple comparisons and providing estimates for the comparisons of interest.

Results

Considering the control predictors, LOG PRIME FREQUENCY (β = 0.006, p = 0.16) and LOG TARGET FREQUENCY (β = −0.02, p = 0.05), and TRIAL NUMBER (β = 0.003, p = 0.79) are not significant predictors of logRT. This means that there is no evidence that participants slowing down or speeding up their responses depending on the frequency of the prime or target, or slow down or speed up responses over the course of the experiment. By contrast, LOG PRIME RT is a significant predictor (β = 0.05, p <0.001), indicating that when a participant responds more slowly to a prime, they also respond more slowly to its target.

For the critical predictors, Table 1 presents raw mean reaction times by condition and priming effects in milliseconds relative to the unrelated baseline. Fig. 3 visualizes the priming effects.

[3] We ran an earlier variable ING priming experiment in parallel on both the same subject pool and on Prolific to check for differences between these populations and found no differences.

Table 1
Experiment 1: Mean response times and priming effects to targets (all in ms) per prime and target type. Standard deviations to RTs are shown in parentheses.

	-ing target		*-in'* target	
	RT (SD)	Priming effect	RT (SD)	Priming effect
Unrelated prime	1001 (119)	NA	1037 (124)	NA
-ing prime	952 (113)	49	976 (116)	61
-in' prime	955 (114)	46	948 (114)	89

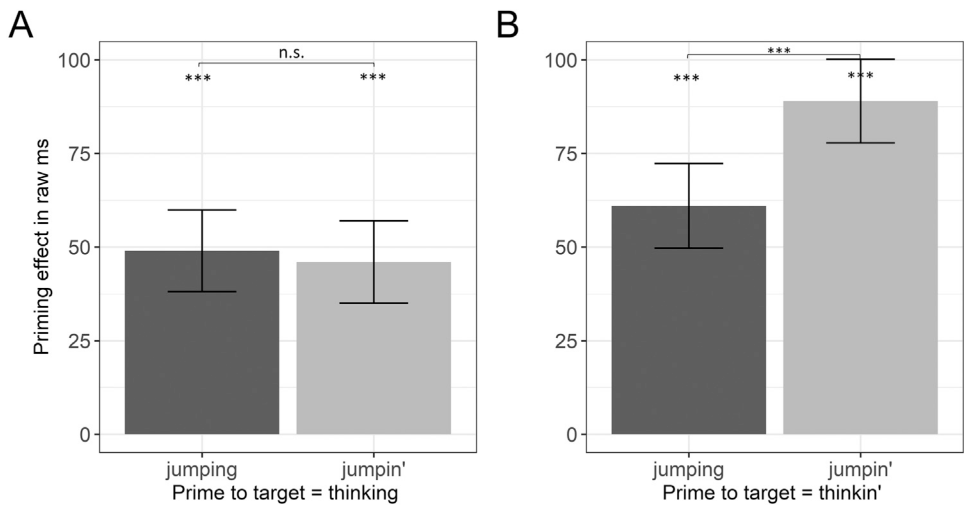

Fig. 3. Experiment 1 results: priming effects to target *thinking* in A, and to target *thinkin'* in B, in raw ms, comparing ING prime conditions to unrelated baseline prime condition (*e.g. jiggle-thinking*).

For *-ing* targets, we observe significant facilitation for *-ing* primes (β = −0.05, p <0.001) and for *-in'* primes (β = −0.05, p <0.001), compared to the unrelated baseline condition. There is no significant difference between these two priming effects (β = 0.003, p = 0.94). For *-in'* targets, there is significant facilitation for *-ing* primes (β = −0.06, p <0.001), and for *-in'* primes (β = −0.09, p <0.001) compared to the unrelated baseline. By contrast to the *-ing* target condition, these two priming effects do differ significantly from each other (β = −0.03, p <0.01).

Experiment 1 discussion

Experiment 1 produced significant ⟨-ing⟩ affix priming in all four critical conditions: the *-ing* and *-in'* forms of the suffix prime both themselves and each other when primes and targets have unrelated stems. This shows that suffixed *-ing* and *-in'* forms share a common representational element: although they have different surface forms and are attached to unrelated verb stems, they are still able to prime one another. This is, to our knowledge, the first demonstration of affix priming across distinct phonological forms, regardless of whether the different forms alternate stochastically or fully predictably. Although significant priming in the cross-variant conditions rules out shared phonological form as the source of the affix priming, it does not shed light on whether the shared representation producing facilitation is morphological or semantic (or both). One approach to disentangling morphological from semantic representations is to examine priming across longer temporal delays and/or intervening linguistic material: semantic priming is typically short-lived, dissipating substantially with one to two intervening items (McNamara, 2005; Wilder et al., 2019). Our first follow-up experiment, Experiment 2, will thus cross the same basic critical conditions of Experiment 1 with the manipulation of whether or not a filler trial intervenes between prime and target.

Although we find priming in all four conditions of Experiment 1, the magnitude of priming across these conditions is not consistent: priming in the *-in'* → *-in'* condition is significantly stronger than the other three conditions. If we look only at *-in'* targets, this result appears consistent with the similarity-based prediction of stronger priming for same-variant prime–target pairs, and inconsistent with the canonicality-based prediction of stronger priming from canonical primes (the reverse of what we find). But, when we also consider *-ing* targets, the similarity-based prediction is not able to explain why a comparable asymmetry (*i.e.*, stronger priming for *-ing* → *-ing* than *-in'* → *-ing*) does not appear. The asymmetrical pattern of priming effects that we observe, then, requires an alternative explanation.

Before proposing a new explanation for the asymmetries observed in Experiment 1, though, we want to know whether they are short-lived or longer lasting, because the answer to that question may point us towards different possible analyses. Variant disparities seen in short-term priming could reflect differences in the online process of word recognition, rather than differences that are encoded in long-term storage in the lexicon. The introduction of a condition with an intervening trial in Experiment 2 thus serves the additional purpose of allowing us to assess the durability of the priming strength asymmetries we have seen here.

Experiment 2

Experiment 2 introduces a condition in which a filler item trial intervenes between prime and target. This 1-intervener condition is compared to a 0-intervener condition with the target trial immediately following the prime trial, which replicates Experiment 1. In order to accommodate both a 0-intervener and 1-intervener condition, while crossing these with all six conditions from Experiment 1 and maintaining a well-powered experimental design, we split Experiment 2 into two sub-experiments: one with only *-ing* targets (Experiment 2a), and one with only *-in'* targets (Experiment 2b).

The goal of Experiment 2 is to find out whether the priming effects that we observe in Experiment 1 persist across a longer period of time with intervening linguistic content, or if they are instead short-lived. Priming effects arising from morphological relationships between

Table 2
Experiment 2a: Mean response times and priming effects to *-ing* targets (in ms) per prime and intervener condition. Standard deviations to RTs are shown in parentheses.

	0-intervener		1-intervener	
	RT in ms(SD)	Priming effect	RT in ms(SD)	Priming effect
Unrelated prime	1021 (150)	NA	1030 (151)	NA
-ing prime	974 (143)	47	1003 (148)	27
-in' prime	982 (147)	39	991 (148)	39

Table 3
Experiment 2b: Mean response times and priming effects to *-in'* targets (in ms) per prime and intervener condition. Standard deviations to RTs are shown in parentheses.

	0-intervener		1-intervener	
	RT in ms(SD)	Priming effect	RT in ms(SD)	Priming effect
Unrelated prime	1050 (162)	NA	1040 (162)	NA
-ing prime	1011 (156)	39	1014 (157)	26
-in' prime	981 (152)	69	1006 (156)	34

prime and target are typically found to be long-lasting, and can persist across an intervening item, while processing facilitation on the basis of semantic or phonological overlap is comparatively short-lived and tends not to persist across intervening items (Dufour, 2008; Kouider & Dupoux, 2009; Lahiri & Reetz, 2010; McNamara, 2005; Wilder et al., 2019). If the only relationship being detected in the affix priming across the *-ing* and *-in'* forms in Experiment 1 is their shared progressive semantics, we would expect the priming to weaken or even disappear entirely in the 1-intervener condition compared to the 0-intervener condition.

In addition to asking whether there is still significant priming within and across-variants at a longer distance, Experiment 2 also allows us to ask whether the asymmetries we observed in immediate affix priming – namely, significantly stronger priming in the *-in'* → *-in'* condition than the other three – are maintained in longer-distance affix priming. While previous work on the question of whether variant recognition asymmetries decay over time has typically used longer distances between prime and target (Soo et al. 2021, Sumner and Samuel 2005, 2009; see also Andruski et al. 1994 and McLennan and Luce 2005 for consideration of much shorter time courses), those studies also typically use lexical repetition, a paradigm that produces very strong and long-lasting priming effects. Because affix priming targets quite small linguistic pieces and is therefore potentially more delicate, we begin with a single intervening trial. If the *-in'* → *-in'* boost is lost in the 1-intervener condition, it would support the idea that the variant form differences are not stored in the lexicon.

Method and analysis

For Experiment 2, 99 participants were recruited to Experiment 2a with *-ing* targets, and 175 were recruited to Experiment 2b with *-in'* targets. Of these, 22 participants were excluded from Experiment 2a and 62 from Experiment 2b for having accuracy scores lower than 80%, so that the analyses include data from 77 participants in Experiment 2a and 113 in Experiment 2b.[4]

We fit separate linear mixed effects models to the data from Experiment 2a and Experiment 2b (see Appendix C). The same trimming method was employed as for Experiment 1. Datapoints with extremely long or short RTs (Experiment 2a: 180 data points, Experiment 2b: 266 data points) were removed leaving 3601 observations for analysis in Experiment 2a, and leaving 5091 observations in Experiment 2b. Finally, model criticism cut the last outliers from the dataset (Experiment 2a: 92 data points, Experiment 2b: 129 data points). The categorical predictors (PRIME TYPE and INTERVENER YES/NO) were Helmert coded such that for PRIME TYPE the first contrast tests the difference between *-ing*-primed and *-in'*-primed RTs and the second contrast tests the difference between unprimed and primed RTs (whereby primed RTs here refers to the average of *-ing*-primed and *-in'*-primed RTs). For INTERVENER YES/NO the contrast tests the difference between RTs in the presence and absence of an intervener. Critical contrasts were once again obtained post-hoc using the `emmeans` package (version 1.7.0) (Lenth, 2022), adjusting p-values using the Tukey method.

Results

Tables 2 and 3 show the raw reaction times to all of the conditions in Experiment 2. Figs. 4 and 5 visualize the priming effects in the critical conditions.

As a reminder, the critical targets in Experiment 2a all end with *-ing*. The three prime type conditions (baseline, *-ing*, and *-in'*) are compared within the two distance conditions of 0-intervener and 1-intervener. The 0-intervener condition replicates the *-ing* target conditions of Experiment 1. In the 0-intervener condition, there are significant priming effects for *-ing* primes ($\beta = -0.05$, $p < 0.001$) and *-in'* primes ($\beta = -0.04$, $p < 0.001$). In the 1-intervener condition, there are significant priming effects for *-ing* primes ($\beta = -0.03$, $p < 0.005$) and for *-in'* primes ($\beta = -0.04$, $p < 0.001$). In both the 0-intervener condition ($\beta = 0.008$, $p = 0.58$) and 1-intervener condition ($\beta = -0.01$, $p = 0.24$) there was no significant difference between the priming effects from *-ing* and *-in'* primes. Of the remaining predictors, TRIAL NUMBER ($\beta = -0.006$, $p = 0.27$) and LOG PRIME FREQUENCY ($\beta = 0.004$, $p = 0.33$) were not significant predictors. By contrast, LOG TARGET FREQUENCY ($\beta = -0.03$, $p < 0.05$) and LOG PRIME RT ($\beta = 0.04$, $p < 0.001$) were significant predictors of logRT.

In contrast to Experiment 2a, the critical targets in Experiment 2b all end with *-in'*. In the 0-intervener condition, we find a significant effect for *-ing* primes ($\beta = -0.04$, $p < 0.001$) and for *-in'* primes ($\beta = -0.03$, $p < 0.001$). The priming from *-in'* primes is significantly larger than the priming from *-ing* primes ($\beta = -0.03$, $p < 0.001$). In the 1-intervener condition, there is significant priming for *-ing* ($\beta = -0.03$, $p < 0.001$) and for *-in'* ($\beta = -0.03$, $p < 0.001$) primes. However, the difference between the prime types is not significant ($\beta = -0.008$, $p = 0.44$). In parallel with Experiment 2a, TRIAL NUMBER ($\beta = -0.004$, $p = 0.47$) and LOG PRIME FREQUENCY ($\beta = 0.0007$, $p = 0.85$) were not significant predictors of logRT, whereas LOG TARGET FREQUENCY ($\beta = -0.03$, $p < 0.05$) and LOG PRIME RT ($\beta = 0.03$, $p < 0.001$) were significant predictors.

Experiment 2 discussion

The 0-intervener conditions in Experiments 2a and 2b successfully replicated the results of Experiment 1. For *-ing* targets (Experiment 2a), we again find that *-ing* and *-in'* primes both produce significant

[4] Experiment 2b required more participants than Experiment 2a due to a higher rate of exclusion at both the participant and trial level.

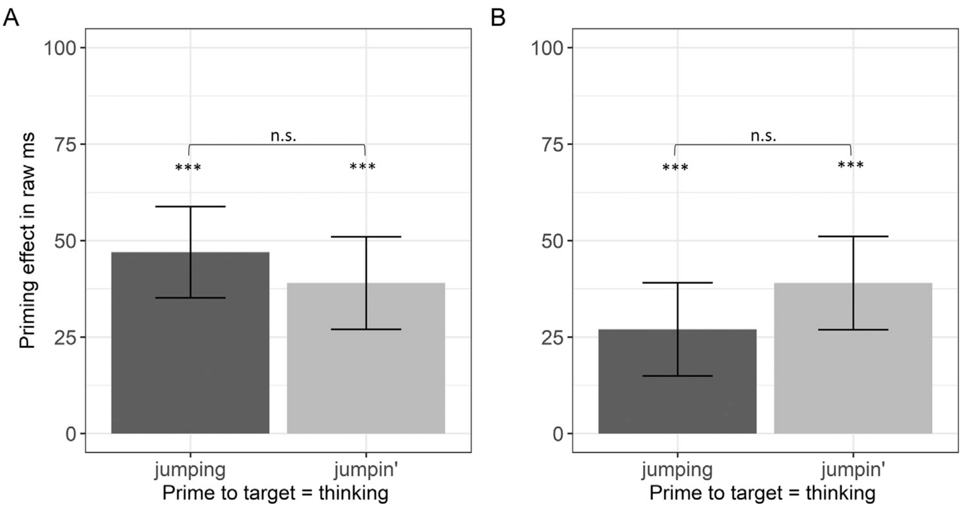

Fig. 4. Experiment 2a: Priming effects in ms for *-ing* and *-in'* primes to *-ing* targets in the 0-intervener (A) and 1-intervener (B) conditions.

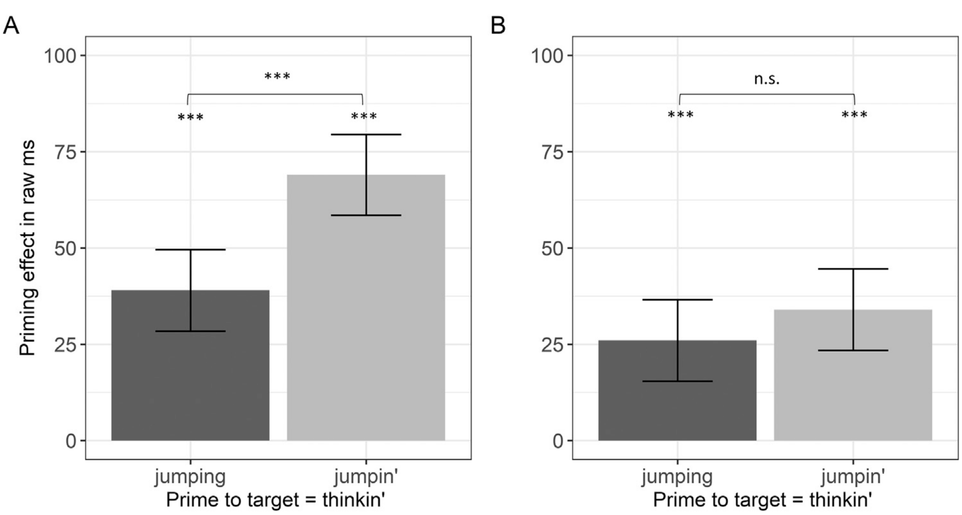

Fig. 5. Experiment 2b: Priming effects in ms for *-ing* and *-in'* primes to *-in'* targets in the 0-intervener(A) and 1-intervener(B) conditions.

priming, but do not differ significantly from each other in the magnitude of those priming effects. For *-in'* targets (Experiment 2b), we also again find significant priming from both variant primes, with *-in'* primes producing a significantly greater speed-up in reaction times. Repeating this overall pattern of effects increases our confidence in the conclusion of Experiment 1 that the variant forms of the ⟨-ing⟩ suffix share some aspect of their representation.

Regarding the durability of these priming effects at a slightly longer distance, we first see that there is still significant priming for all four critical prime/target combinations in the 1-intervener conditions of Experiments 2a and 2b. In other words, an intervening item does not eliminate the affix priming effect that we found in Experiment 1, irrespective of prime and target variant forms. This is consistent with both variants being associated with an independent morphological representation of ⟨-ing⟩ suffix, coinciding with earlier studies finding that morphological priming is relatively long-lasting (Wilder et al., 2019), except that in the present study the effect is found with an affix, not a stem. The durability of the affix priming is less consistent with an analysis where the only point of shared representation between the suffix variants is their semantic meaning, because semantic priming is not expected to persist across intervening material.

In contrast, the presence of an intervener does appear to attenuate the extra boost to the *-in'*→ *-in'* priming that was observed in both Experiment 1 and the 0-intervener conditions of Experiment 2. With an intervening item, we are no longer able to detect any asymmetries between the different variants as primes and targets. We thus consider the possibility that the particularly strong priming effect seen in the *-in'*→ *-in'* condition actually reflects a combination of two facilitatory processes: the basic affix priming effect that arises in all critical conditions and is stable across both distances, and a separate facilitatory process that produces an extra "boost" for the *-in'*→ *-in'* pairs but is no longer active when prime and target are further apart.

One possibility is that *-in'* → *-in'* prime–target pairs might share some additional element that can speed recognition when primed. The phonological rule account for variable ING, outlined above, supplies one such possible difference: if *-in'* is derived from underlying *-ing* via a phonological rule, then in this condition alone, prime and target both contain the output of this rule application. In the basic task of (unprimed) word recognition, faster reaction times to canonical forms might arise if, as Bürki et al. consider for schwa-deletion, "non-canonical forms must be recovered from the surface form via a rule-based process" (2018:494). There is some evidence for this kind of inference process: in a visual world study, Farris-Trimble and Tessier (2019) find that listeners are slower to fixate words where the allophonic rules of flapping (/t/ → [ɾ]) and Canadian Raising (/aɪ/ → [ʌɪ]) have applied. This is consistent with our informal observation (not tested statistically because the comparison is across sub-experiments) that unprimed *-in'* targets seem to be recognized more slowly than unprimed *-ing* targets. But rather than weakening how effective non-canonical forms are as primes, this seeming disadvantage may convert into an advantage when that recovery process subsequently needs to be repeated. In other words, the strength of the *-in'* → *-in'* priming effect might arise from priming of the reverse-engineering process itself.

If this explanation is on the right track, then we should be able to separate out this rule-reversal priming from the effect of affix priming. Our second follow-up experiment, Experiment 3, aims to elicit rule-reversal priming in the absence of affix priming.

Experiment 3

As we highlighted in Fig. 2, on a phonological account of variable ING, the phonological rule would generate surface *-in'* forms in progressive verbs and monomorphemes alike. This predicts that the putative priming of the phonological rule reversal, to which we suggest attributing the extra strength of *-in'* → *-in'* priming in Experiments 1 and 2, should remain apparent even with *-in'* primes that are monomorphemic, such as *awnin'*. In other words, *awnin'* should prime *thinkin'* through priming of the phonological rule reconstruction, without reference to morphological structure. However, the asymmetrical nature of this effect should also be apparent here: *awning* should not prime *thinking*, because *awning* contains neither the progressive suffix/semantics shared by both ING variants, nor the phonological rule changing /ŋ/ to /n/. We thus ran a second pair of follow-up experiments to test these two hypotheses. Experiment 3a asks whether a monomorpheme like *awnin'* primes a suffixed verb form like *thinkin'*, compared to an unrelated baseline. Experiment 3b asks the same question but for the *-ing* variant: that is, whether *awning* primes *thinking* compared to an unrelated baseline.

The story we put forward in the discussion of Experiment 2 carries an additional prediction that we also test here. We suggested that the particularly strong *-in'* → *-in'* priming seen in Experiment 1 was actually a combination of two priming effects: priming of the affix regardless of variant form, and priming of the phonological rule deriving the *-in'* form. If these two effects can indeed combine additively in this way, then priming from *awnin'* to *thinkin'* should be weaker than priming from *jumpin'* to *workin'*, because the latter has both sources of facilitation while the former has only one. Therefore, in both Experiment 3a and Experiment 3b, we also include a progressive ING verb of the same variant as a second type of prime.

Materials

The critical stimuli for Experiment 3a and Experiment 3b consist of 16 prime–target pairs. Like the materials developed for Experiment 1 and Experiment 2, all primes and targets are disyllabic. The 16 targets all consist of progressive verbs, like *jumping/jumpin'*. The primes for Experiment 3a and Experiment 3b consist of either progressive verbs with an *-ing/-in' e.g. jumping/jumpin'* (*-in'* versions in Experiment 3b and *-ing* counterparts in Experiment 3a), monomorphemic words with an *-ing/-in'* like *awning/awnin'*(*-in'* versions in Experiment 3b and *-ing* counterparts in Experiment 3a), or an unrelated disyllabic verb (*e.g. jiggle*). Note that in contrast to Experiment 1 and Exp 2 there are only 16 prime–target pairs available for use in Experiment 3a and Experiment 3b. This is caused by the low number of ING-final monomorphemic disyllabic words available in the English language that are not homophonous with progressive verbs (*e.g. ceiling* and *sealing* cannot be used).[5] The monomorphemes used in Experiment 3a and Experiment 3b can be found in Appendix B.

Method and analysis

To make up for the lower number of available items for analysis, 151 participants were recruited to Experiment 3a with *-in'* primes and targets, and 129 to Experiment 3b with *-ing* primes and targets. Of these, 33 participants were excluded from Experiment 3a and 25 from Experiment 3b for having accuracy scores lower than 80% such that 118 participants remained available for analysis in Experiment 3a and 103 in Experiment 3b. The data for Experiment 3a and Experiment 3b were analysed separately using linear mixed effects models (see Appendix C). The same trimming procedure was used as in Experiment 1 and Experiment 2a and Experiment 2b. All data points with extremely long or short RTs were removed from the dataset (Experiment 3a: 75 data points, Experiment 3b: 31 data points). Model criticism cut the last outliers from the dataset (Experiment 3a: 33 data points, Experiment 3b: 30 data points) leaving in Experiment 3a 1462 data points for analysis, and in Experiment 3b 1154 data points.

Results

Table 4 shows the raw reaction times to the conditions in Experiment 3a and Experiment 3b. Figs. 6 show the priming effects in the parallel critical priming conditions.

First, in Experiment 3a the targets were progressive disyllabic verbs ending in *-in'* (*e.g. thinkin'*), and there were three prime types: unrelated baseline (*e.g. jiggle*), progressive *-in'* verb with an unrelated stem (*e.g. jumpin'*), and monomorphemic word ending with *-in'* (*e.g. awnin'*). These shall henceforth be called the Unrelated, Progressive, and Monomorpheme conditions. The Progressive condition replicates the -in'-in' conditions found in Experiment 1 and Experiment 2b. Linear mixed effects regression models were fit separately for Experiment 3a and Experiment 3b, in the same way as they were done for Experiment 1, Experiment 2a, and Experiment 2b. The fixed effects were PRIME TYPE (Helmert coded), and as numeric control predictors TRIAL NUMBER, LOG PRIME FREQUENCY, LOG TARGET FREQUENCY, and LOG PRIME RT. The categorical predictor PRIME TYPE was Helmert coded such that the first contrast tests the difference between Progressive-primed and Monomorpheme-primed RTs, and the second contrast tests the difference between unprimed and primed RTs (whereby primed RTs here refers to the average of -ing-primed and -in'-primed RTs). The critical comparisons of interest were obtained post-hoc using the emmeans package (version 1.7.0) (Lenth, 2022), adjusting p-values using the Tukey method.

In Experiment 3a there is significant priming for both Progressive ($\beta = -0.10$, $p < 0.001$) and Monomorphemic ($\beta = -0.04$, $p < 0.001$) primes. The priming effect found for Progressive primes is significantly larger than that for Monomorphemic primes ($\beta = -0.07$, $p < 0.001$). Of the remaining predictors, LOG PRIME RT ($\beta = 0.03$, $p < 0.001$) was the only significant predictor, with LOG PRIME FREQUENCY ($\beta = -0.0007$, $p = 0.88$), LOG TARGET FREQUENCY ($\beta = -0.02$, $p = 0.46$) and TRIAL NUMBER ($\beta = -0.01$, $p = 0.11$) not contributing.

In Experiment 3b there is significant priming for the Progressive condition ($\beta = -0.04$, $p < 0.001$), but *not* for the Monomorpheme

[5] Due to the low number of monomorphemic words available in English, and for statistical power reasons, we decided to include the items *wedding* and *bedding*, which are both most frequently used in their nominal form, although historically they come from the verbs *to wed* and *to bed*. In order to ensure that the effects in this experiment were not driven by the morphological status of these two forms, we post-hoc removed *wedding* and *bedding* from the dataset and found that the raw RTs in all conditions were within a few milliseconds of the original results, making it unlikely that the effect is driven by these two items.

Table 4
Experiment 3a and 3b: Mean response times and priming effects to progressive targets (all in ms) per prime and target type. Standard deviations to RTs are shown in parentheses.

	Experiment 3a: *-in'* only		Experiment 3b: *-ing* only	
	RT (SD)	Priming effect	RT (SD)	Priming effect
Unrelated prime	1106 (341)	NA	979 (254)	NA
Progressive prime	998 (307)	108	942 (243)	37
Monomorphemic prime	1066 (330)	40	963 (250)	16

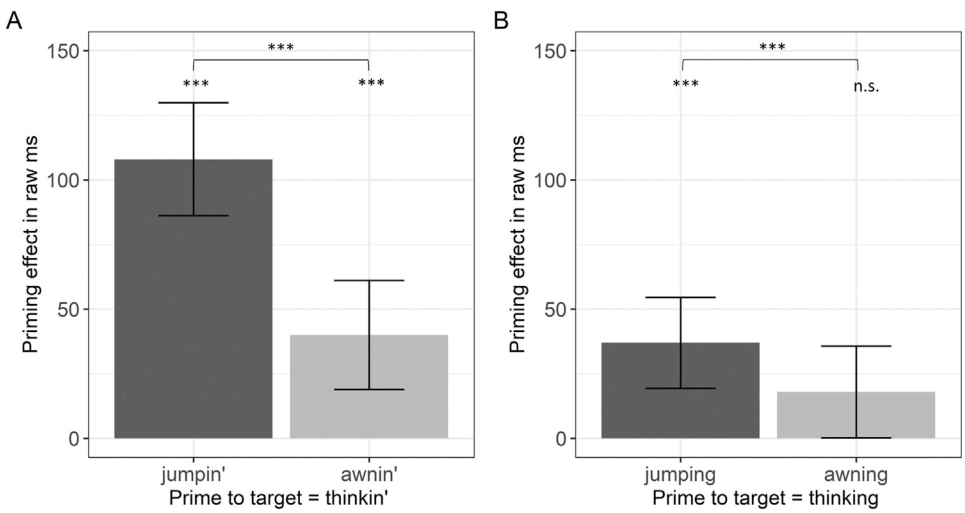

Fig. 6. Experiment 3a (panel A) and Experiment 3b (panel B): Priming effects in ms for progressive *-in'/-ing* and monomorphemic *-in'/-ing* primes to progressive *-in'/-ing* targets.

condition (β = −0.015, p = 0.088). The difference between the Progressive and Monomorpheme condition is significant (β = −0.023, p < 0.005). Parallel to Experiment 3a, here we see a significant effect for LOG PRIME RT (β = 0.03, p < 0.001), but not for the remaining three control predictors: LOG PRIME FREQUENCY (β = −0.006, p = 0.11), logTargetFrequency (β = −0.002, p = 0.92), or TRIAL NUMBER (β = −0.003, p = 0.66).

Experiment 3 discussion

The results from both Experiment 3a and Experiment 3b support the pair of predictions that we made on the basis of the phonological account of ING. The finding from Experiment 3a that *awnin'* primes *workin'* is as we suggested under an analysis where the listener needs to reverse-engineer the phonological rule that produces the *-in'* variant in both monomorphemes and suffixed verbs, and immediately doing this reverse-engineering again makes it easier. Furthermore, the result that the strength of priming in the *awnin'* → *workin'* condition is significantly weaker than the strength of priming in the *jumpin'* → *workin'* condition is consistent with the proposal that the former type of prime–target pair shares only the rule-reversal whereas the latter type benefits from two sources of facilitation: rule-reversal and the affix priming effect that we saw in Experiments 1 and 2.

On the account we are developing here, the phonological rule is only relevant for the *-in'* form, as the *-ing* form is the underlying form stored in the lexicon. Therefore, we did not predict priming from *awning* to *working*. Our failure to detect significant priming in this condition is consistent with this prediction. We do still see affix priming from *jumping* to *working*, as expected.

Discussion

To briefly recap our results, Experiment 1 found significant affix priming within and across ING variants, with the strongest priming effect in pairs where both prime and target contain *-in'*. In addition to replicating these results, Experiment 2 found that while the affix priming was sustained across an intervening trial for all prime–target combinations, the boost for the matched *-in'* pairs was no longer evident at that distance. Experiment 3 found that between monomorphemic primes and complex targets, there is priming between *-in'* forms (*awnin'*→ *thinkin'*), albeit to a lesser degree than from complex primes (*jumpin'*→ *thinkin'*), but there is not evidence for priming between *-ing* forms (*awning*→ *thinking*). We will discuss our interpretation of the affix priming effect and *-in'* asymmetry in turn, then consider alternative explanations, broader theoretical implications, and further directions.

Priming within and across allomorphs

We found significant affix priming in every condition where prime and target both contain the ⟨-ing⟩ suffix, throughout all three experiments, regardless of the variants used and the distance between prime and target. This is, to our knowledge, the first demonstration of affix priming for the ⟨-ing⟩ suffix and the first demonstration of affix priming across different surface forms of an affix.

The finding of a substantial affix priming effect when the prime and target both contain the canonical *-ing* form is itself worth noting, even though it may seem straightforward. For spoken word recognition, the reliable detection of affix priming, particularly for inflectional affixes, is relatively novel (*e.g.* Goodwin Davies & Embick, 2020). Most prior work on affix priming was done in the visual modality, and the results are fairly mixed (i.a. Duñabeitia et al., 2008; Giraudo & Grainger, 2003; Marslen-Wilson et al., 1996). Most of these studies find reliable processing facilitation for derivational affixes (*e.g. blackness* → *shortness*) but not for inflectional affixes. The ⟨-ing⟩ suffix studied in this paper has a mixed status with respect to the derivation/inflection distinction, since it appears both in gerunds (nominals with category-change, characteristic of derivation) and in progressive verb forms (part of the verbal paradigm, hence more inflectional). It thus occupies an intermediate position between "heavy" derivational affixes like *-ness* and the inflectional plural *-s*; see Goodwin Davies and Embick (2020) for pertinent discussion. When we consider the *-in'* → *-in'* condition, Experiments 1 and 2 additionally make it clear that affix priming is not restricted to standardly-pronounced words: we are equally able to detect a strong and significant affix priming effect when the affix appears with a non-canonical pronunciation variant.

The experimental literature on how morphologically-complex words are recognized has, as discussed above, been concerned with the question of whether affixes are represented as independently-represented morphological units, or whether putative effects of morphological relatedness emerge from semantic and phonological features of whole-word representations. We should be careful to note that the experiments in the current study were not designed to disentangle these possibilities directly: the strongest evidence for independent morphological representation comes from studies with both phonological and semantic control conditions, which our Experiments 1 and 2 lack (in fact, it is not obvious what such control conditions would look like in these experiments). The basic, canonical *-ing* → *-ing* priming result here could thus arise from either the priming of an independent ⟨-ing⟩ morpheme, or from some combination of the shared semantic content and phonological form of *-ing*.

Importantly, though, Experiments 1 and 2 also find robust cross-variant priming: *-ing* facilitates the processing of *-in'* and vice versa. This finding is of theoretical interest because it suggests that the *-ing* and *-in'* forms have some representational relationship to each other. The same caution as above applies: this result does not, strictly speaking, differentiate between abstract morphological representation and shared semantic content across the different forms of the suffix. However, the cross-variant conditions do make clear that the representation shared by prime and target cannot be *solely* the surface phonological identity, since the variants are by definition different in their phonological form.

The durability of affix priming in Experiment 2, where all four critical conditions exhibit significant priming even with an intervening trial between prime and target, is also suggestive with respect to the representation of the ⟨-ing⟩ suffix. Both phonological and semantic priming typically give rise to short-lived processing facilitation that does not last across intervening items, whereas morphological priming persists across intervening items (i.a. Radeau et al., 1995). As discussed in Wilder et al. (2019), the presence of morphological priming (*e.g. frogs* → FROG) at distances where neither semantic nor phonological priming are found suggests a morphological locus of this effect, in the shared stem *frog*. Our findings in Experiment 2 raise the further possibility that morphological identity might also be detectable with a suffix like ⟨-ing⟩.

The -in' asymmetry

An unexpected finding from Experiment 1, replicated in Experiment 2, was that when both prime and target contain the *-in'* variant, the resultant priming is significantly stronger than for the other three variant combinations. Unlike the presence of affix priming, which remained robust across an intervening filler trial, the boost to this *-in'*→ *-in'* condition did not persist when the prime and target were not immediately adjacent (in the 1-intervener condition of Experiment 2b). We thus suggested that the *-in'*→ *-in'* condition might be benefiting from two sources of facilitation: the same affix-priming effect as in the other three conditions, plus a short-lived effect specific to *-in'* repetition.

Specifically, we proposed that this latter *-in'*-specific effect might be a speedup from repeating what we have called rule-reversal: recovering the underlying *-ing* form from the surface *-in'* form that resulted from a phonological rule. The derivation of *-in'* from underlying *-ing* corresponds to what we called a phonological locus for variable ING. A key point here is that the *-in'*→ *-in'* condition is the only one in which both prime and target recognition require this reversal process. Other potential linguistic sources of variant asymmetries do not correctly pick out this condition as the odd one out. If simple variant repetition strengthened priming, we should also have seen a boost in the *-ing* → *-ing* condition to parallel the *-in'* → *-in'* boost. And if prime non-canonicality inhibited priming, we should see weaker priming from *-in'* to both target types, instead of no difference to *-ing* targets and *stronger* priming to *-in'* targets.

Experiment 3 revealed an additional respect in which the variants are processed asymmetrically. When prime–target pairs have matching variants but *mismatching* morphological structures – specifically, monomorphemic primes and suffixed targets – only the *-in'* pairs produce evidence for cross-word-type priming. This is as we predicted on the analysis that the *-in'*→ *-in'* condition in Experiments 1 and 2 involved two distinct sources of facilitation, one of which is specific to complex words (affix priming) and one of which is specific to *-in'* forms (rule reversal). By using primes that could not induce affix priming because they do not contain an affix, we separated out these two sources of facilitation. And when there is no affix priming at play, rule reversal repetition should facilitate target recognition only in pairs where in fact the rule reversal is active and repeated, namely the *-in'* pairs. It is also important that Experiment 3a showed that cross-word-type *-in'* priming is significantly weaker than *-in'* priming in complex word pairs. Since our suggestion is that rule reversal facilitation creates the *-in'*→ *-in'* boost in Experiments 1 and 2 by combining additively with the affix priming effect that is present in all four conditions, we also expect that a condition with rule reversal repetition alone should show weaker facilitation than a condition with both rule reversal repetition and affix priming.

Do the results support a phonological locus for ING?

A central motivation for selecting variable ING for this study was that it exemplifies the representational ambiguities that can arise when variation occurs in affixes. Relying on evidence from conversational speech data, the sociolinguistic literature on variable ING has not been able to resolve the question of whether ING variation in complex words arises from the same process as ING variation in monomorphemic words. In complex words, the variation could in principle arise from variable allomorphy: a probabilistic alternation between stored forms of the affix itself; what we have called a morphological locus for ING. Or, variable ING could involve a stochastic phonological process that has some probability of changing the nasal place of articulation whenever the relevant phonological environment appears, which happens to include the progressive suffix. We have called this a phonological locus for ING.

The combined results of Experiments 1–3 have, in our view, supplied a compelling new line of evidence in support of a phonological locus for ING, with all ING environments having unique representation of an underlying /ŋ/ in the lexicon. A morphological locus for ING would not predict the priming across monomorphemic and complex words that we see in Experiment 3a. Moreover, a phonological locus of ING introduces an intrinsic asymmetry between the variants: the asymmetry between an underlying form and the phonologically-derived surface form. This asymmetry, and the phonological rule involved in the *-in'* form, play a key role in our account of the asymmetries we see: the boost that is unique to the *-in'*→ *-in'* condition in Experiment 1, the decay of that boost at a distance while the affix priming effect remains stable in Experiment 2, and the isolation of the cross-category priming to the *-in'* forms in Experiment 3.

On the analysis where the *-in'* variant is derived via phonological rule from the underlying *-ing* form, the answer to whether the variants of variable ING are stored in the lexicon is no. In an important sense, this result is deeply compatible with the kinds of analyses advanced by the canonicality advantage literature, in that it involves words having a single stored form, variant pronunciations arising outside of the lexicon, and the basic word recognition process suffering some cost as a result of the non-canonical form's mismatch to the lexical representation. However, there is also an equally important sense in which the results are not as we expected from the canonicality advantage literature: rather than the delay in prime recognition undermining the strength of the priming effect, we have argued that the rule-reversal process can itself be facilitated through repetition, thereby converting a prime-recognition disadvantage into an extra speedup on the target.

This result stands in contrast to some results from past studies with similar priming designs. For example, LoCasto and Connine (2002) used an auditory repetition priming task to examine word-medial schwa deletion in English words such as *camera/cam'ra*. They found that targets with a canonical word-medial schwa were primed more strongly by a canonical prime than a non-canonical (schwa-less) prime, whereas non-canonical targets were primed to an equivalent degree by canonical and non-canonical primes. They interpreted this result as evidence that canonical pronunciations are easier to process than non-canonical ones, at least with respect to facilitating upcoming instances of the same phonological variable. This is the opposite of our finding of equivalent priming to canonical targets and a variant repetition advantage to non-canonical targets, underscoring the point that our results, although asymmetric across variants, are *not* as predicted by the canonicality advantage literature. However, they are also not as predicted by models that predict recognition equivalence between variants, since the *-in'*→*-in'* boost is a notable asymmetry. Our results thus contribute a new pattern that is not predicted by existing accounts that we know of. While we have offered an account that we think could explain our own results, the disparate results that have been found across this literature remain to be reconciled.

A possible alternative

Finally, our discussion to this point has focused on weighing the evidence for competing representational analyses in the framework we used to set up our investigation: one in which a morphological locus of ING is aligned with dual representation and a phonological locus of ING is aligned with unique representation. Assessed within this framework, the phonological locus/unique mapping account is better supported. But are there other potential *kinds* of explanations for our overall pattern of results? As we have pointed out, any explanation for the observed *-in'* asymmetries needs to pick out the *-in'*→ *-in'* condition as distinct from the other three variant-pair combinations. The most promising alternative explanation that has this property, as suggested to us by a reviewer, is one where what is being facilitated through repetition in the *-in'*→ *-in'* condition is not the reconstruction of the underlying form from the rule output, but rather the recognition of a saliently "nonstandard" form (in a sociostylistic sense) as meriting a "word" response in the lexical decision task.

We do have evidence that many participants are at first inclined to give a "nonword" response to these items, in the form of the very elevated error rates to *-in'* primes of 40% in the pilot. Such responses could represent true failures of lexical access, or could represent the participants' assessment that such forms do not meet the relevant standard for wordhood in the experimental task. The extensive quantitative sociolinguistic literature on ING leaves us with little doubt that our participants hear and use *-in'* variants every day, and there is no reason to doubt that there is successful retrieval of such forms from the lexicon when they are processed. But we might also reasonably assume that participants have strong stylistic expectations that isolated words presented in an experiment should appear in their canonical forms. The fact that we are able to reduce the error rate from 40% to around 20% in the full experiments through instructions explaining that some words may be pronounced in casual ways suggests that participants can learn to overcome this expectation, even if it is not trivially easy to do so. As a result, when a participant has just given a "word" response to the nonstandard *-in'* form, they might find it easier to produce the same response to that form immediately afterwards.

One small piece of evidence that may weigh against such an interpretation is that participants do not appear to improve their error rates to *-in'* items over the course of the experiment. For example, the accuracy rate to *-in'* primes is 81% in the first half of Experiment 2b and, if anything, goes down very slightly, to 78%, in the second half. If the issue is that participants need to overcome the expectation that only canonical forms are appropriate to the experimental context, we might predict that the participants adjust that expectation over time as the inputs containing *-in'* accumulate and the participants get more practice overcoming their original expectation. This does not seem to happen. Unfortunately, this observation also leaves us without an easy way of understanding the discrepancy between accuracy rates to *-ing* and *-in'* items at all, highlighting how little is understood about the processing of variation in SWR. Ultimately, we note that this type of explanation would be compatible with the kind of representations we have discussed here, even though it attributes the *-in'* boost itself to a different cause.

Conclusion

This study investigated the mental representation of variable ING, which arises in both suffixes and monomorphemic words and thus implicates a number of theoretical issues. The appearance of variable ING in different word types has made it difficult to resolve whether the variation has a phonological or morphological locus. We connected that question with a broader theoretical debate from the SWR literature over whether words with pronunciation variants have only a unique stored form in the lexicon, or whether multiple variant forms are lexically represented. We argued that the results of three auditory primed lexical decision experiments best support an account where variable ING involves unique lexical representation with the variation arising from a phonological process in all word types. Further work is needed to investigate the role of stylistic expectations in recognizing variable ING words and to reconcile our novel pattern of priming results with other priming patterns in the literature on the role of variation in SWR.

Consent

Written informed consent was obtained from experimental participants, under University of Pennsylvania Institutional Review Board Protocol #820633.

CRediT authorship contribution statement

Yosiane White: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **David Embick:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Meredith Tamminga:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data, R scripts, and stimulus lists are available at: https://osf.io/9vure/?view_only=3375dbe797294a029547e9438bae71f7.

Acknowledgements

Many thanks are due to Charlotte Vaughn, Ruaridh Purse, Lacey Wade, Bill Labov, Gillian Sankoff, and past and present members of the Language Variation and Cognition Lab at the University of Pennsylvania for their feedback on this project.

Funding

This research was supported in part by a University Research Foundation grant from the University of Pennsylvania, United States of America to Meredith Tamminga and David Embick, and by an Integrated Language Science and Technology (ILST) small grant sponsored by MindCORE from the University of Pennsylvania, United States of America to Yosiane White.

Appendix A. Critical stimuli Experiment 1, Experiment 2a, and Experiment 2b

Experiment 1 used both of the below target types, and all three prime types (-ing, -in', and Control) in a within-participant design. Experiment 2a used the -ing targets, and all three prime types, whereas Experiment 2b used exclusively -in' targets with the same set of primes.

ItemN	ingTargets	inTargets	ingPrime	inPrime	Control
C1	stealing	stealin	bending	bendin	wrestle
C2	crawling	crawlin	holding	holdin	busy
C3	itching	itchin	roaring	roarin	hassle
C4	nudging	nudgin	shunning	shunnin	riddle
C5	smearing	smearin	clashing	clashin	vary
C6	steering	steerin	rising	risin	fiddle
C7	twitching	twitchin	gliding	glidin	worry
C8	cooking	cookin	breaking	breakin	argue
C9	hugging	huggin	clanging	clangin	pickle
C10	soaking	soakin	risking	riskin	tackle
C11	tweaking	tweakin	clogging	cloggin	heckle
C12	bumping	bumpin	coping	copin	cripple
C13	dreaming	dreamin	carving	carvin	limit
C14	leaping	leapin	burping	burpin	tumble
C15	shoving	shovin	bluffing	bluffin	trumpet
C16	stopping	stoppin	saving	savin	level
C17	weeping	weepin	skimming	skimmin	lobby
C18	boasting	boastin	launching	launchin	burrow
C19	draining	drainin	bouncing	bouncin	empty
C20	mending	mendin	charring	charrin	huddle
C21	snoozing	snoozin	hoisting	hoistin	facet
C22	swirling	swirlin	forging	forgin	study
C23	yielding	yieldin	belching	belchin	scurry
C24	croaking	croakin	smirking	smirkin	toggle
C25	jogging	joggin	shrugging	shruggin	wrinkle
C26	speaking	speakin	hiking	hikin	pocket
C27	paying	payin	crying	cryin	file
C28	clapping	clappin	whooping	whoopin	grapple
C29	dripping	drippin	filming	filmin	copy
C30	pasting	pastin	hoping	hopin	trouble
C31	sipping	sippin	limping	limpin	stymy
C32	sweeping	sweepin	flaming	flamin	puppet
C33	chewing	chewin	mowing	mowin	equal
C34	brushing	brushin	folding	foldin	throttle
C35	drowning	drownin	ruining	ruinin	tarnish
C36	scanning	scannin	waltzing	waltzin	hurry
C37	spinning	spinnin	messing	messin	pity
C38	swooning	swoonin	skidding	skiddin	tidy
C39	blinking	blinkin	pecking	peckin	giggle
C40	docking	dockin	clucking	cluckin	boggle
C41	knocking	knockin	bragging	braggin	angle
C42	stacking	stackin	linking	linkin	cackle
C43	sighing	sighin	spraying	sprayin	foil
C44	climbing	climbin	blooming	bloomin	shimmy
C45	dropping	droppin	drumming	drummin	envy
C46	mopping	moppin	bribing	bribin	levy
C47	swooping	swoopin	delving	delvin	cobble
C48	growing	growin	plowing	plowin	towel
C49	burning	burnin	wasting	wastin	fancy
C50	glaring	glarin	jousting	joustin	bully
C51	mixing	mixin	waxing	waxin	carry
C52	scowling	scowlin	munching	munchin	nestle
C53	lagging	laggin	basking	baskin	crackle
C54	teaching	teachin	washing	washin	bury
C55	clicking	clickin	trucking	truckin	bargain
C56	faking	fakin	lacking	lackin	wiggle
C57	picking	pickin	begging	beggin	muddle
C58	thinking	thinkin	working	workin	jiggle
C59	jumping	jumpin	gleaming	gleamin	sample
C60	napping	nappin	gulping	gulpin	triple

Appendix B. Critical stimuli Experiment 3a and Experiment 3b (*-in'* versions used in Experiment 3a, *-ing* counterparts used in Experiment 3b)

ItemN	Target	Progressive Prime	Monomorphemic Prime	Control
C1	stealing	bending	tiding	wrestle
C2	crawling	holding	wedding	busy
C3	itching	roaring	darling	hassle
C4	nudging	shunning	herring	riddle
C5	smearing	clashing	starling	vary
C6	steering	rising	lemming	fiddle
C7	twitching	gliding	inning	worry
C8	cooking	breaking	sibling	argue
C9	hugging	clanging	sterling	pickle
C10	soaking	risking	evening	tackle
C11	tweaking	clogging	bedding	heckle
C12	bumping	coping	inkling	cripple
C13	dreaming	carving	shilling	limit
C14	leaping	burping	fledgeling	tumble
C15	shoving	bluffing	awning	trumpet
C16	stopping	saving	dumpling	level

Appendix C. Model output for Experiments 1–3

	log(TargetRT)		
Predictors	*Estimates*	*CI*	*p*
Intercept	6.89	6.86 – 6.91	**<0.001**
PrimeType-helmert 1: -ing vs -in' primes	0.01	0.00 – 0.02	**0.030**
PrimeType-helmert 2: unrelated vs primed	0.06	0.05 – 0.07	**<0.001**
TargetType-helmert: -ing vs in' targets	-0.02	-0.03 – -0.01	**<0.001**
Trial number (z-scored)	0.00	-0.02 – 0.03	0.791
Prime log frequency (z-scored)	0.01	-0.00 – 0.02	0.163
Target log frequency (z-scored)	-0.02	-0.05 – -0.00	**0.046**
Prime log RT (z-scored)	0.05	0.04 – 0.05	**<0.001**
Interaction: PrimeType 1 vs TargetType	-0.03	-0.05 – -0.01	**0.008**
Interaction: PrimeType 2 vs TargetType	-0.03	-0.05 – -0.01	**0.008**
Random Effects			
σ^2	0.02		
$\tau_{00\ targetStem}$	0.01		
$\tau_{00\ Participant}$	0.01		
$N_{Participant}$	57		
$N_{targetStem}$	60		
Observations	2948		
Marginal R^2 / Conditional R^2	0.114 / 0.499		

Model output for Experiment 1

Model formula for Experiment 1: *log(TargetRT) ~ PrimeType.helm * TargetType.helm + zTrial + zlogPrimeFrequency + zlogTargetFrequency + zlogPrimeRT + (1|Participant) + (1|TargetStem)*.

	log(TargetRT)		
Predictors	*Estimates*	*CI*	*p*
Intercept	6.91	6.88 – 6.94	**<0.001**
PrimeType-helmert 1: -ing vs -in' primes	0.00	-0.01 – 0.01	0.652
PrmieType-helmert 2: unrelated vs primed	0.04	0.03 – 0.05	**<0.001**
Intervener-helmert: intervener yes/no	0.02	0.01 – 0.02	**<0.001**
Trial number (z-scored)	-0.01	-0.02 – 0.00	0.270
Prime log frequency (z-scored)	0.00	-0.00 – 0.01	0.329
Target log frequency (z-scored)	-0.03	-0.05 – -0.01	**0.011**
Prime log RT (z-scored)	0.04	0.03 – 0.04	**<0.001**
Interaction: PrimeType 1 vs Intervener	0.02	-0.00 – 0.04	0.061
Interaction: PrimeType 2 vs Intervener	-0.01	-0.03 – 0.01	0.249
Random Effects			
σ^2	0.02		
$\tau_{00\ Participant}$	0.01		
$\tau_{00\ targetStem}$	0.01		
$N_{Participant}$	77		
$N_{targetStem}$	60		
Observations	3509		
Marginal R^2 / Conditional R^2	0.072 / 0.559		

(a) Model output for Experiment 2a

	log(TargetRT)		
Predictors	*Estimates*	*CI*	*p*
Intercept	6.92	6.90 – 6.95	**<0.001**
PrimeType-helmert 1: -ing vs -in' primes	0.02	0.01 – 0.03	**<0.001**
PrmieType-helmert 2: unrelated vs primed	0.04	0.03 – 0.05	**<0.001**
Intervener-helmert: intervener yes/no	0.01	-0.00 – 0.01	0.106
Trial number (z-scored)	-0.00	-0.01 – 0.01	0.471
Prime log frequency (z-scored)	-0.00	-0.01 – 0.01	0.847
Target log frequency (z-scored)	-0.03	-0.05 – -0.00	**0.028**
Prime log RT (z-scored)	0.03	0.03 – 0.04	**<0.001**
Interaction: PrimeType 1 vs Intervener	-0.02	-0.04 – -0.00	**0.013**
Interaction: PrimeType 2 vs Intervener	-0.02	-0.04 – -0.01	**0.002**
Random Effects			
σ^2	0.02		
$\tau_{00\ Participant}$	0.01		
$\tau_{00\ targetStem}$	0.01		
$N_{Participant}$	113		
$N_{targetStem}$	60		
Observations	4962		
Marginal R^2 / Conditional R^2	0.067 / 0.502		

(b) Model output for Experiment 2b

Model formula for Experiment 2a and Experiment 2b: *log(TargetRT) ~ PrimeType.helm*IntervenerYesNo. helm + zTrialNumber + zlogPrimeFrequency + zlogTargetFrequency + zlogPrimeRT+(1|Participant) + (1|TargetStem)*

	log(TargetRT)		
Predictors	*Estimates*	*CI*	*p*
Intercept	6.96	6.91 – 7.02	**<0.001**
PrimeType-helmert 1: monomorpheme vs progressive	0.07	0.05 – 0.08	**<0.001**
PrimeType-helmert 2: unrelated vs primed	0.07	0.06 – 0.08	**<0.001**
Trial number (z-scored)	-0.01	-0.03 – 0.00	0.106
Target log frequency (z-scored)	-0.00	-0.01 – 0.01	0.883
Prime log frequency (z-scored)	-0.02	-0.07 – 0.03	0.413
Prime log RT (z-scored)	0.04	0.03 – 0.05	**<0.001**
Random Effects			
σ^2	0.01		
$\tau_{00\ Participant}$	0.01		
$\tau_{00\ targetStem}$	0.01		
$N_{Participant}$	118		
$N_{targetStem}$	16		
Observations	1462		
Marginal R^2 / Conditional R^2	0.084 / 0.690		

(a) Model output for Experiment 3a

	log(TargetRT)		
Predictors	*Estimates*	*CI*	*p*
Intercept	6.87	6.82 – 6.92	**<0.001**
PrimeType-helmert 1: monomorpheme vs progressive	0.02	0.01 – 0.04	**0.001**
PrimeType-helmert 2: unrelated vs primed	0.03	0.01 – 0.04	**<0.001**
Trial number (z-scored)	-0.00	-0.02 – 0.01	0.657
Target log frequency (z-scored)	0.01	-0.00 – 0.02	0.109
Prime log frequency (z-scored)	-0.00	-0.05 – 0.04	0.919
Prime log RT (z-scored)	0.03	0.03 – 0.04	**<0.001**
Random Effects			
σ^2	0.01		
$\tau_{00\ Participant}$	0.01		
$\tau_{00\ targetStem}$	0.01		
$N_{Participant}$	103		
$N_{targetStem}$	16		
Observations	1408		
Marginal R^2 / Conditional R^2	0.046 / 0.673		

(b) Model output for Experiment 3b

Model formula for Experiment 3a and Experiment 3b: *log(TargetRT) ~ PrimeType.helmert + zTrial + zlogPrimeFrequency + zlogTargetFrequency + zlogPrimeRT + (1|Participant) + (1|TargetStem)*

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