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Differences between morphological and repetition priming in auditory lexical decision: Implications for decompositional models

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ABSTRACT

A natural way of probing the effects of morphology on lexical processing is to directly compare morphological priming, for which primes and targets share a stem but are mismatched in morphological structure (e.g., *frogs* → *frog*), with outright repetition priming (e.g., *frog* → *frog*). However, work making this comparison has reported no difference between these two types of priming. Importantly, the reported non-differences have been found in the visual domain. Here, we investigate morphological (Morph) versus repetition (Rep) priming in two auditory primed lexical decision experiments. Using the English plural suffix -/z/, we compare Rep priming with Morph priming for both singular and plural target conditions (e.g., *frog/frogs* → *frog*, *frog/frogs* → *frogs*). Overall, we find robust priming in both Rep and Morph conditions. However, for both singular and plural targets, there is consistent evidence that Rep priming is greater than Morph priming at early lags of 0 and 1 intervening items. This facilitation decreases with an increasing number of intervening items. Comparisons with phonological and semantic controls demonstrate that this pattern cannot be attributed solely to shared form or meaning. We interpret these findings in a decompositional model of morphological processing. The robust facilitation in Morph and Rep conditions is attributed to the activation of a shared stem representation. The convergence of Morph and Rep is attributed to a diminishing episodic trace related to morphological recombination.

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1. Introduction

1.1. *Morphological representation and the processing of inflected words*

One of the central issues in the study of lexical processing concerns how *morphological relatedness* is represented in the minds of speakers. Given that speakers of English (the language studied here) produce and comprehend pairs of words like *frog* and *frogs* for example, there must be some mental representation of the fact that these words are connected in ways that other pairs of words (e.g., *shark/cheese*, or *wombats/plasma*, …) are not. Theoretical frameworks differ greatly with respect to how such relationships are represented. At one end are *decompositional* theories, in which morphologically complex words like *frogs* are broken down (or *decomposed*) in such a way that *frogs* **contains** *frog* (or, more abstractly, such that *frog* and *frogs* each contain an element FROG). Fully decompositional theories (e.g., Marantz, 2013; Taft, 2004; cf. Embick, 2015) posit this type of relation for all complex words. At the other end of the spectrum are approaches that generalize whole-word storage, such that all words are represented in memory (Butterworth, 1983; Norris & McQueen, 2008). Intermediate positions are found, according to which certain words are decomposed while others are not, depending on some set of criteria (e.g., regularity, productivity, or frequency; see Marslen-Wilson, 2007 for review). To the extent that whole-word storage theories posit some sort of morphological “link” among related words in memory, they differ from a certain type of connectionist model, in which morphological representation is eschewed across the board (e.g., Baayen, Milin, Đurđević, Hendrix, & Marelli, 2011; Gonnerman, Seidenberg, & Andersen, 2007; Plaut & Gonnerman, 2000). In models like these, putative effects of morphological representation or processing are derivative of shared semantic and phonological relatedness, perhaps interacting with each other.

If words are decomposed into their constituent morphemes, it is expected that we should be able to detect effects associated with morphological processing and activation. In the specific decompositional model proposed in Taft (2004), there are in fact multiple stages to consider: the process of decomposing a word into constituent morphemes; the process of accessing those morphemes; and the process of recombining the morphemes into the complex form. The distinctness of these stages will play an important role in interpreting the findings of this paper, a point we examine in our general discussion.

On the face of it, an obvious way of looking for effects of morphological processing (broadly construed) is to compare Morph priming (*frogs* → *frog*) with Rep priming (*frog* → *frog*). To the extent that there are differences in facilitation between Morph and Rep priming, there would be evidence for morphological processing, since the primes in question differ crucially in the presence of a morpheme in Morph that is absent in Rep priming. Hypothetical Morph/Rep differences could then be probed further in terms of the predictions of specific models, to see, for example, if the facilitation differences were driven by differences in the activation level of the stem in Morph and Rep, or by effects of the recombination stage, and so on.

As it turns out, using Morph/Rep priming to probe morphological processing is much more complicated than the sketch in the preceding paragraph would indicate. There are two primary reasons for this—one theoretical and one deriving from seemingly contradictory results found in prior studies targeting Morph/Rep priming comparisons.

1.2. *Theoretical predictions of decompositional models*

The predicted relationship between Morph and Rep priming in decompositional models is a complex question. At a first glance, it looks like a decompositional approach would predict essentially the same facilitation for Morph and Rep. The reasoning is as follows: in Rep priming, a stem like *frog* is activated, and, when repeated as a target, response time is facilitated due to *frog* having been activated as a prime. In Morph priming, a prime *frogs* is decomposed into constituent morphemes *frog* and *-s*. All else equal, the target *frog* is expected to be facilitated to the same extent here as it is in Rep priming; in both conditions, *frog* is activated in the prime prior to presentation of the target.

The “all else equal” qualification is (as is often the case) crucial to the line of reasoning immediately above. To see why, it is important to return to the properties of specific decompositional models. The argument for identity in facilitation in Morph and Rep is based on a view of decomposition that takes only the activation of the stem into account. As noted above, the decompositional theory proposed by Taft (2004) posits additional stages in morphological processing: decomposition (the process of segmenting the input into morphemes, based on formal properties); and recombination (reassembly of constituent pieces into a complex whole). If either of these processes induced effects on morphological processing that are detectable with priming, then Morph and Rep priming facilitation are **not** necessarily expected to be equal. The reason for this is clear—the Morph priming condition involves a prime with an additional morpheme compared to the target, unlike the Rep priming condition.

We will return to the decomposition and recombination stages in our general discussion, where it will be argued that the complex set of results to be presented from our two experiments can be understood as implicating the effects of the recombination stage in particular.

1.3. *Results of prior work*

There are relatively few studies that directly compare Morph and Rep priming. And, interestingly, the majority of those that make this comparison appear to support the “simple” decomposition story outlined above, in that they report equal facilitation for Morph and Rep. However, and crucially, an examination of prior work reveals what appears to be a modality difference: the studies reporting equal Morph and Rep facilitation were conducted in the visual modality, while the one study that finds differences between Morph and Rep used auditorily presented words.

Turning to specific prior findings, facilitatory priming effects for complete repetition, normally attributed to the

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activation strength of a representation, are well-established cross-linguistically in visual and auditory modalities (e.g., Forster & Davis, 1984; Scarborough, Cortese, & Scarborough, 1977). Morphological priming (sometimes called *stem priming* in the literature) is also reported in visual and auditory modalities for both inflectional and derivational morphology in a range of languages (e.g., Crepaldi, Rastle, Coltheart, & Nickels, 2010; Kouider & Dupoux, 2009; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Murrell & Morton, 1974; Napps, 1989; Napps & Fowler, 1987; Rastle, Davis, & New, 2004; Stanners, Neiser, Hernon, & Hall, 1979). What is novel in the work reported here is the direct comparison between Morph and Rep priming in a tightly controlled study.

As mentioned earlier, few studies directly compare Rep and Morph; to our knowledge, this is attempted in Stanners et al. (1979), Fowler, Napps, and Feldman (1985), Forster, Davis, Schoknecht, and Carter (1987) and Kouider and Dupoux (2009). Stanners et al. (1979) used the visual modality to investigate Morph and Rep priming effects, and suggested that Morph priming is equivalent to Rep priming for English inflectional variants. Specifically, they report no differences between the two using English inflected primes (*-s*, *-ed*, and *-ing*) in a long distance (6–15 intervening items, measured in terms of words intervening between prime and target) primed visual lexical decision task. They interpret this result as consistent with there being a lexical entry corresponding to the stem that is wholly responsible for the priming effects (these findings are replicated in Fowler et al., 1985, Experiment 1).

Using a masked priming paradigm in the visual modality, Forster et al. (1987, Experiment 7) also compare repetition and morphological priming for inflectional variants. They find equivalent effects in both conditions (≈36/37 msec). Their morphological condition consisted of irregular inflectional variants, namely irregular verb inflections (e.g., *creep* → *crept*) and irregular plurals (*women* → *woman*) with either the prime or target appearing as inflected.

Using the auditory modality, Kouider and Dupoux (2009) report facilitatory effects of Rep and Morph priming for masculine/feminine allomorphic variants in French (e.g., “cold”, *froid/froide* → *froid*) at long distances at which no facilitation was found for phonological and semantic primes. Consistent differences between Rep and Morph priming were found at very long lags (means of 18 and 72 intervening items) in a primed auditory lexical decision task, with Rep showing more facilitation than Morph priming. However, facilitatory effects for Rep and Morph priming converged in their final experiment, when the lag was increased to a mean of 144 intervening items and when the speaker producing the stimuli was switched between prime and target. Similar to Stanners et al. (1979), Kouider and Dupoux (2009) attribute the convergence of Rep and Morph priming effects as evidence for an abstract stem representation shared between inflectional variants. To account for the differences between Rep and Morph priming observed at shorter lags, they hypothesize that the contribution of inflection is episodic in nature; that is, in the same way that episodic properties such as voice and speech rate may reduce facilitation relative to absolute repetition, the presence of a morpheme is regarded as a property stored in episodic memory that distinguishes the Morph primes from their targets. At longer lags, where differences between Rep and Morph priming are not found, they suggest that the episodic representation registering the presence of the morpheme has decayed, such that only the more abstract properties of the stem are active; this makes Rep and Morph priming effectively identical.

Considering these prior studies together raises a number of questions. Most fundamentally, they report conflicting results concerning the effects of inflectional morphology in priming at shorter distances. On the face of it, there are some differences between the studies that might explain the apparent contradiction. The most obvious, perhaps, is that the different results are due to the different modalities employed (Stanners et al., 1979: visual; Kouider & Dupoux, 2009: auditory). There are indeed reasons to believe that inflectional elements would be processed differently in the visual and auditory modalities; in auditory presentation, the signal unfolds incrementally, whereas in the visual modality, the entire signal is presented instantaneously. This contrast is particularly important in work which investigates the role of suffixes, which come late in auditory presentation but are perceptible from the outset in visual presentation (e.g., Rastle et al., 2004). Even if subphonemic co-articulatory cues are present in auditorily presented words prior to the actual suffix, it is necessary for the speech signal to unfold before these become apparent to the listener, unlike in visual processing.

We note in passing that beyond the differences in modality, which is of direct interest to us, there are further additional differences in the types of words that are employed in the studies reviewed above. Stanners et al. tested a range of English verbal inflectional variants whereas Kouider and Dupoux tested French nominal and adjectival variants inflected for gender. Notably, Kouider and Dupoux's materials have morphemes with allomorphic stem changes (e.g., vowel differences in *brun*/bʁœ̃/ *vs brune*/bʁyn/). Our studies do not include allomorphic variation.

The results reviewed above are especially puzzling when viewed from the perspective of the lags involved; Kouider and Dupoux (2009) find Morph/Rep differences at very long lags relative to the short repetition distances employed by Stanners et al. (1979), who find no Morph/Rep differences.

In summary, much remains to be investigated about how Morph and Rep priming relate to one another.

2. The present study

2.1. *Goals*

Building on the main points reviewed above, the studies reported here were designed with three primary goals in mind. The first concerns the basic question of whether Morph and Rep priming produce different amounts of facilitation in the auditory modality in the first place. For ease of reference, we use $\mathcal{F}$ to denote “priming facilitation”, with subscripts to indicate condition: thus $\mathcal{F}_{\text{morph}}$ is “facilitation in morphological priming” and $\mathcal{F}_{\text{rep}}$ “facilitation in repetition priming”.

As noted in Section 1.3, Kouider and Dupoux's auditory priming study shows Morph versus Rep differences (unlike visual studies), with $\mathcal{F}_{\text{rep}} > \mathcal{F}_{\text{morph}}$; our own pilot studies revealed the same pattern of Morph/Rep differences as well. Our first goal was

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to look as carefully as possible at these differences. We therefore included conditions with Morph and Rep primes for singular targets: *frogs* → *frog* and *frog* → *frog*.

In Section 1.2, it is pointed out that a decompositional model with both decomposition and recombination stages could in principle account for Morph/Rep differences at either one of the stages. In order to look carefully at this issue, we introduced a condition in which **plural** targets are preceded by singular or plural primes, for example *frog* → *frogs* (Morph) and *frogs* → *frogs* (Rep). The reasoning is as follows: if there is a general cost of decomposition that reduces facilitation, then $\mathcal{F}_{\text{morph}} > \mathcal{F}_{\text{rep}}$ would be predicted for plural targets. This is because the prime/target pairs in this Rep condition have two morphemes, whereas the Morph condition pairs have only one. On the other hand, the recombination stage could also be responsible for Morph/Rep differences. If this were the case, then the reverse pattern of facilitation ($\mathcal{F}_{\text{rep}} > \mathcal{F}_{\text{morph}}$) is predicted. In the Rep condition (*frogs* → *frogs*), there would be priming of both the stem *frog* and prime and target would also have the same recombination process that combines *frog* and -*s*. In the Morph condition on the other hand, there would be priming only for the stem, since prime and target differ with respect to recombination.

Fig. 1 illustrates the conditions that are summarized above:

It is worth emphasizing that our Rep and Morph conditions relate to standard uses of “repetition priming” and “morphological priming” in the literature but the inclusion of inflected targets is novel.

Finally, we employed a distance manipulation in which primes and targets occur with either 0, 1, or 5 intervening words. This allows us to examine the temporal dynamics of Morph/Rep differences. Recall from above that these differences might be episodic in nature, and that (while the role of episodic memory remains to be made precise) a temporal manipulation will allow us to see if Morph/Rep differences are maintained over time, or whether facilitation in the two conditions converges.

In order to rule out the possibility that the effects we find are driven by phonological or semantic overlap, Experiments 1 and 2 incorporate phonological and semantic control conditions respectively. The details of these controls are introduced along with the experiments below.

2.2. *Choice of materials*

Before proceeding to the experiments, a few words are in order concerning (i) the notions of identity that are relevant to Morph/Rep comparisons in general, and (ii) the choice of morphology (plural -s) that is used in this particular paper.

A useful starting point for understanding why Morph and Rep priming effects should be examined together is the observation that there are different ways in which words may be related to one another, reflecting different sub-parts of the linguistic system. At one extreme of relatedness is the identity relation. As revealed by Rep priming studies, response times to a word like *frog* are greatly facilitated when immediately preceded by *frog*, whether in the visual or auditory modalities (e.g., Forster & Davis, 1984; Scarborough et al., 1977). Interestingly, the notion of identity that is involved in experiments of this type can be separated into distinct components. In the most typical setup for auditory repetition priming, identity is absolute—the same sound-file is employed as both prime and target. As measured in terms of response time, absolute identity priming of this type is more robust than that observed when two distinct tokens of a word from different speakers are used as prime and target (*frog*$_1$ and *frog*$_2$, cf. McLennan & Luce, 2005; Bradlow, Nygaard, & Pisoni, 1999; Goldinger, 1996). These talker-switch experiments employ primes and targets that are identical as words, with the same semantics and morphology (phonology as well, if the speakers are from the same dialect), but which differ acoustically due to the inherent variation manifested between two different speakers. What these (and related) manipulations show is that word tokens can be identical in different ways, and that these differences sometimes have detectable effects in priming paradigms.

Regarding the morphology itself, both of the studies reported here make use of the English plural morpheme, and some comments are in order concerning this choice. As noted above, several factors (acoustic, phonological, morphological, semantic) must be taken into account when calculating the relations between words. Along these lines, an inflectional affix, like the plural employed here, may have morpho-syntactic, morpho-phonological, and/or morpho-semantic contributions to the representation of the “morphologically complex” whole. In particular, material from the stem and affix may be organized into a hierarchical structure, arranged into a phonological structure, and/or composed into a semantic representation.

In this paper, experimental stimuli are singular and plural English nouns which inflect for plurality with the voiced -/z/ realization of the plural suffix. There are several reasons for choosing /z/-plurals in investigating morphological relatedness. First, -/z/ is the default plural morpheme, applying to novel nouns (e.g., Berko, 1958), which highlights its status as a productive morpheme. Next, it has reflexes in the syntax of English through triggering agreement on verbs, therefore showing it has processing consequences (i.e., the syntactic information provided by the suffix needs to be kept in memory in order to determine the proper agreement on the verb). Furthermore, by restricting our investigation to the voiced allomorph of the regular plural, we are able to keep phonological realization consistent, removing unwanted effects that might arise from (morpho-)phonological alternations. Finally, the semantic contribution of the regular plural morpheme is transparent and fairly consistent throughout the pairs chosen, which can be seen in the Appendix.

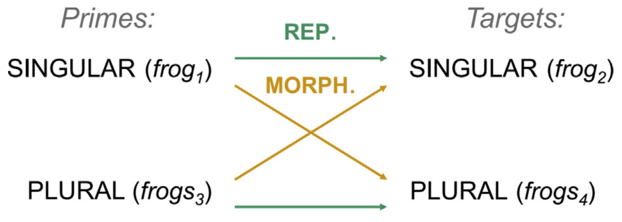

Fig. 1 – Illustration of the Repetition and Morphological conditions of Experiment 1. Subscripts indicate distinct tokens.

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3. Experiment 1

Experiment 1 is comprised of two sub-experiments.[1] The first is designed to analyze differences between Rep priming and Morph priming, as described in Section 2.1, through the inclusion of singular and plural targets and singular, plural, and unrelated primes. The combination of these primes and targets allows us to directly compare Rep priming (*frog* → *frog*/*frogs* → *frogs*) with Morph priming (*frog* → *frogs*/*frogs* → *frog*). The inclusion of the unrelated primes (Baseline: *smoke* → *frog*/*frogs*) allows us to analyze the magnitude of both Rep and Morph priming effects, while comparing the Rep to the Morph conditions reveals the impact of the inflectional affix on both singular and plural targets.

The second sub-experiment of Experiment 1 is included to examine the effect of phonological similarity and how it compares to morphological similarity. It contains two target types which are analogous to the stem sub-experiment in that they involve the same degree of phonological similarity (i.e., the presence or absence of a final phoneme) but crucially lack any morphological relationship. We call these target types “substring” (e.g., *gray*) and “superstring” (e.g., *grape*). The conditions Rep, Phon, and Baseline were constructed similarly to the stem sub-experiment.

For both sub-experiments, targets are kept constant across the three conditions (Rep, Morph/Phon and Baseline) removing extraneous variance in statistical comparisons. Additionally, different sound-files were used for prime and target in the Rep conditions, eliminating a potential confound in which the Rep conditions involve exact phonetic repetition with identical sound-files whereas the Morph/Phon conditions involve different sound-files and therefore no exact phonetic repetition. The conditions of Experiment 1 are summarized below in Table 1.

By varying the number of stimuli intervening between prime and target (0, 1, and 5 intervening items), we examine the patterns of priming-effect attenuation between conditions. Specifically, we analyze how the magnitude of Rep versus Morph/Phon facilitation decreases across an increased number of intervening items. Our implementation of distance as a fixed number of intervening items provides an additional advantage: by not relying on averaging across distance ranges, we are able to get a clear idea of the early time-course of facilitation attenuation across these conditions.

Overall, there are 18 conditions each for the stem and phonological sub-experiments, crossing Target condition (Singular *vs* Plural/Superstring *vs* Substring) × Prime condition (Rep, Morph/Phon, *vs* Baseline) × Distance (0, 1, and 5 intervening items).

3.1. *Method*

3.1.1. *Stimuli*

The singular and plural stimuli comprising the Rep and Morph conditions were made from 90 singular noun stems. Stems were chosen according to two criteria: (a) inflecting with the voiced plural allomorph /z/ and (b) more frequent in the singular than in the plural variant, chosen as some theories of morphology predict different storage of forms which are more frequent in the singular than in the plural (e.g., Baayen, Dijkstra, & Schreuder, 1997). An additional 90 singular nouns were selected as primes for the Baseline condition. We used Latent Semantic Analysis (LSA: Dennis, 2007) to restrict semantic relatedness (mean = .064, range = [−.04, .2]) between the targets and the Baseline primes. These primes were selected to match the Rep primes on frequency using the Lg10CD measure from SUBTLEX-US (Brysbaert & New, 2009, mean Rep = 2.41, mean Baseline = 3.07) and in phonological neighborhood density using the relevant measure from the English Lexicon Project (Balota et al., 2007, mean Rep = 17.18, mean Baseline = 18.02).

Table 1 – Prime and target conditions in the two sub-experiments of Experiment 1.

Sub-experiment	Prime condition		Target condition	
Stem	Baseline	*smoke*	Singular	*frog*
	Morphological	*frogs*		
	Repetition	*frog*		
	Baseline	*smoke*	Plural	*frogs*
	Morphological	*frog*		
	Repetition	*frogs*		
Phonological	Baseline	*mug*	Substring	*gray*
	Phonological	*grape*		
	Repetition	*gray*		
	Baseline	*mug*	Superstring	*grape*
	Phonological	*gray*		
	Repetition	*grape*		

The stimuli for the phonological sub-experiment were similarly created from 36 substring/superstring pairs (e.g., *gray* and *grape*). These pairs were also selected to be minimally semantically related using LSA [mean = .073, range = (−.05, .2)] and matched on frequency using the Lg10CD measure (mean prime = 2.54, mean target = 2.52). An additional 36 singular nouns were selected as primes for the Baseline condition, again using LSA to restrict semantic relatedness between prime/target pairs [mean = .105, range = (−.05, .30)].

Non-word filler stimuli were included, as required for a lexical decision task. These non-words, 252 in total, were restricted to be monosyllabic and phonotactically licit in English. The presentation of stimuli was counterbalanced in a Latin Square design such that every subject encountered each target once and encountered an equal number of pairs in each prime/target condition. Since three prime conditions (Rep, Morph, and Baseline) had two identical targets (singular *vs* plural) with three distance conditions (0, 1, or 5 intervening stimuli), we created 18 experimental lists. The Rep condition primes and targets were distinct sound-files for both the stem and phonological sub-experiments. Each list had a 50% word to non-word ratio among the 504 items per list. All stimuli were recorded in a soundproof booth by a male speaker of General American English.

3.1.2. *Participants*

In return for course credit, 177 participants from the University of Pennsylvania provided informed consent and completed the study in the fall semester of 2017.

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[1] Results from Experiment 1 are reported as Experiment 4.2 in Goodwin Davies, 2018.

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3.1.3. *Procedure*

Participants were instructed to indicate whether each sound they heard was a word of English as quickly and as accurately as possible. Sounds were presented with a random interstimulus interval (ISI) between 900 and 1100 msec, measured from the end of the sound-file or the participant's response, whichever was later. Participants first responded to 10 practice trials (50% non-words) before being sequentially assigned to one of the 18 experimental lists. The experiment was run online using the experimental presentation software Ibex (Drummond, 2017). As a result, participants used their own auditory presentation equipment and responded using their keyboard. Participants were given two breaks throughout the experiment. Stimuli prime/target pairs were dispersed evenly and randomly among the resulting three blocks in Experiment 1 and consecutive trials were restricted to not be in the same experimental condition. Additionally, the distance manipulation was accomplished by randomly interleaving distance pairs together such that each block contained the same number of prime–target pairs in each distance condition.

3.2. *Results*

Of the 177 participants, 20 participants were removed because they indicated that they were not native speakers of North American English. An additional seven subjects were removed due to accuracy across all stimuli below 70%. Furthermore, three items were removed due to overall accuracy below 50%. From the remaining 150 participants, we removed trials where responses to the prime or target stimuli were inaccurate. After fillers were removed, trials with response time (RTs) less than 300 msec or greater than 2500 msec were deemed unreasonable and removed, resulting in the removal of 4.4% of the data. 1.4% of the data was removed following the a-priori minimal trimming procedures for specific subjects and items which were not normally distributed, as indicated by the Shapiro test for normality; a procedure recommended by Baayen and Milin (2010). The percentage of data removed for this experiment is well under the maximum amount of removal cited by Ratcliff (1993) and even under the sample experiment presented in Baayen and Milin (2010).

While the analyses presented in this paper focus solely on interpreting reaction time data, common with the lexical decision task as error rates are generally quite low, we will note here some general trends in the accuracy data. Overall, singular and plural targets were responded to with 89% and 91% accuracy respectively. Visualizing the corresponding error rates in Table 2, we see that targets in the Rep and Morph conditions were responded to more accurately than the Baseline condition, which is expected from the literature on Rep and Morph priming. For the phonological sub-experiment, substring and superstring targets were responded to with 86% and 94% accuracy, which mirrors what we see in Table 2; namely, that accuracy was globally worse for substring targets, although this does not seem to interact with the prime conditions.

In this and the following sections, we analyzed log-transformed RT using linear mixed effect models (lme4 package, implemented in R). Random effects for all models were optimized following Bates, Kliegl, Vasishth, and Baayen (2015). *p*-Values were calculated using the Satterthwaite approximation for degrees of freedom and we report as significant only effects with *p*-values less than .05. Millisecond effect sizes were calculated using percentages of the fixed-effect predictors, given that the dependent variable was logarithmically transformed. Fig. 2 shows predicted log-transformed RTs from separate models fitted to each Target Condition (models discussed in detail below). For each Target Condition, predicted log-transformed RT is plotted for each Prime Condition at each Distance.

Table 2 – Target error rates for Experiment 1.

Sub-experiment	Prime condition	Target condition	Target error rate (%)
Stem	Baseline	Singular	11.2
		Plural	14.3
	Morphological	Singular	6.8
		Plural	8.7
	Repetition	Singular	7.8
		Plural	8.8
Phonological	Baseline	Substring	16.5
		Superstring	6.4
	Phonological	Substring	14.4
		Superstring	7.6
	Repetition	Substring	12.0
		Superstring	3.2

3.2.1. *Stem sub-experiment*

Prime condition was treatment-coded so that Baseline versus Morph and Morph versus Rep conditions were compared; the intercept being the Baseline condition; a type of coding scheme that is sometimes called “repeated contrasts”. Distance was also treatment-coded, comparing intervening item distances of 1 versus 0 and 5 versus 1, with the 0 intervener condition as the intercept.

In Table 3, we report the percentage increase in RT from the interpretation of the full singular model and the full plural model coefficients. Fig. 3 shows mean facilitation for Morph and Rep conditions for each target type. We constructed separate models for the singular and plural targets summarized in Tables 4 and 5 respectively.

Significant main effects of the two prime condition contrasts were found in both singular and plural models. Starting with the singular model, the results indicate that, at immediate distances, Morph was significantly faster than Baseline ($\beta = -.25$, $p < .001$) and that Rep was significantly faster than Morph ($\beta = -.08$, $p < .001$). In order to evaluate whether prime conditions were significantly different at 1 and 5 interveners, we constructed additional separate models. In the model of responses at 1 intervener, the Morph condition was significantly faster than the Baseline ($\beta = -.12$, $p < .001$) and the Rep condition was significantly faster than the Morph condition ($\beta = -.07$, $p < .001$). A similar pattern of significance was found in the model of responses at 5 interveners – Morph was faster than Baseline ($\beta = -.11$, $p < .001$) and Rep was marginally faster than Morph ($\beta = -.03$, $p = .062$).

A similar overall pattern was observed in the plural model. The results indicate that, at immediate distances, Morph was

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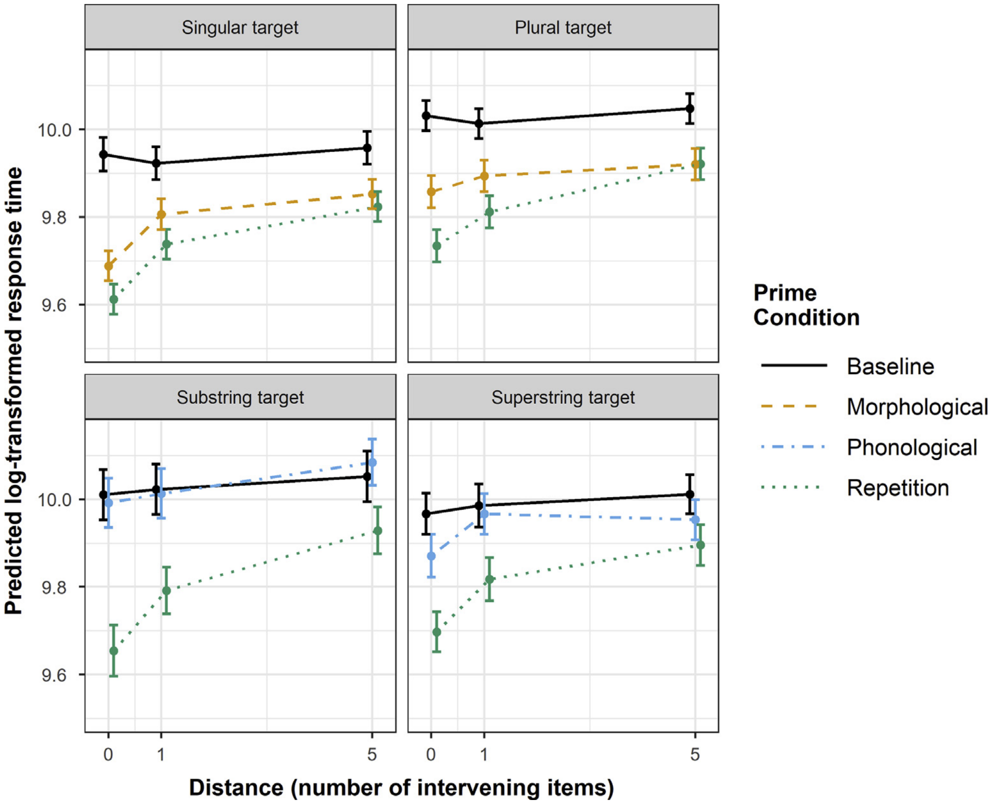

Fig. 2 – Predicted log-transformed RTs from the models for each target type in Experiment 1.

significantly faster than Baseline ($\beta = -.17$, $p < .001$) and that Rep was significantly faster than Morph ($\beta = -.12$, $p < .001$). To evaluate whether prime conditions were significantly different at 1 and 5 interveners, we again constructed additional separate models. At 1 intervener, the Morph condition was significantly faster than the Baseline ($\beta = -.12$, $p < .001$) and the Rep condition was significantly faster than the Morph condition ($\beta = -.07$, $p < .001$). At 5 interveners, Morph was significantly faster than Baseline ($\beta = -.13$, $p < .001$). The comparison between Rep and Morph was not significant however ($\beta = .01$, $p = .606$); different from the singular model.

We found significant interaction effects between the distance and prime condition contrasts in both models. For singular and plural targets, significant differences in slopes exist between Baseline and Morph conditions at 0 versus 1 intervening items (Singular: $\beta = .14$, $p < .001$; Plural: $\beta = .05$, $p = .007$) whereas no such interaction was found at 1 versus 5 intervening items (Singular: $\beta = .01$, $p = .605$; Plural: $\beta = -.01$,

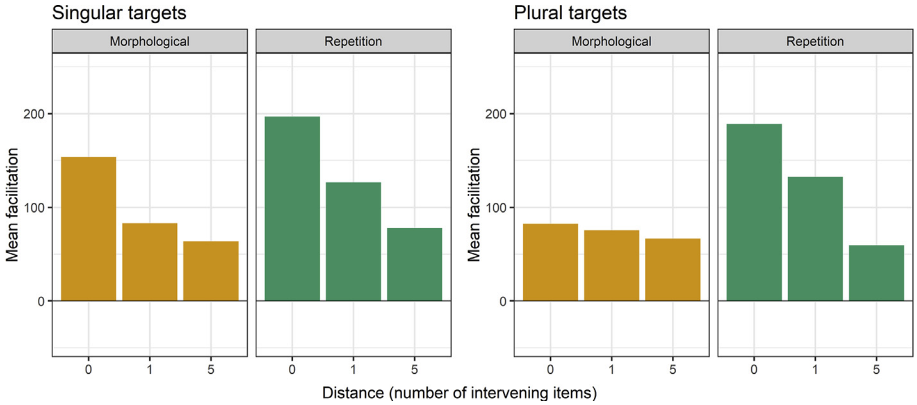

Fig. 3 – Facilitation plots for each target type in the stem sub-experiment of Experiment 1 (calculated as raw mean Baseline RT – raw mean RT for each Distance × Prime–target relationship condition).

Table 3 – Summary of transformed betas from the stem sub-experiment of Experiment 1.

Target condition	Prime condition	Number of interveners		
		0	1	5
Singular targets	Morphological	16.19	7.75	7.06
	Repetition	5.14	4.63	1.97
Plural targets	Morphological	11.34	7.95	8.43
	Repetition	8.19	5.50	.06

Morphological = % faster than Baseline; Repetition = % faster than Morphological.

$p = .705$). This is due to responses to the unrelated Baseline remaining relatively constant between 0 and 1 interveners, whereas facilitation effects diminished over time for the Morph and Rep conditions. In the plural model, the interaction between Morph and Rep conditions was significant at both 0 versus 1 ($\beta = .038$, $p = .04$) and 1 versus 5 intervening items ($\beta = .08$, $p < .001$), indicating a different rate of priming reduction between the two conditions at these distances.

We also constructed a large model which includes both target types in order to investigate whether target type interacted with prime condition and/or distance manipulations. In this model, there was a significant main effect of target condition ($\beta = .07$, $p = .006$) indicating that responses to plural targets were 5.4% slower than responses to singular targets.

Table 4 – Experiment 1: singular model summary.

	Log-transformed RT		
	Betas	CI	*p*-Values
Fixed effects			
(Intercept)	9.96	9.92, 10.00	**<.001**
Distance			
0 *vs* 1 interveners	−.02	−.05, .01	.188
1 *vs* 5 interveners	.04	.01, .06	**.019**
Prime–target relationship			
Morphological *vs* Baseline	−.25	−.28, −.23	**<.001**
Repetition *vs* Morphological	−.08	−.10, −.05	**<.001**
Stem frequency	−.02	−.03, .00	.054
Target duration	.07	.05, .08	**<.001**
Inter-stimulus interval	.01	.00, .02	**.005**
Target phonological neighborhood	0	−.02, .01	.683
Log-transformed previous RT	.07	.06, .08	**<.001**
Transitional probability of plural suffix	.01	.00, .03	.157
Trial number	−.02	−.03, −.02	**<.001**
Previous trial accuracy	−.01	−.04, .01	.440
Previous trial lexicality	.01	−.01, .03	.257
Participant gender	.05	−.01, .10	.057
Distance (0 *vs* 1) × P–t rel. (Morph *vs* Baseline)	.14	.10, .17	**<.001**
Distance (1 *vs* 5) × P–t rel. (Morph *vs* Baseline)	.01	−.02, .04	.605
Distance (0 *vs* 1) × P–t rel. (Rep *vs* Morph)	.01	−.03, .04	.705
Distance (1 *vs* 5) × P–t rel. (Rep *vs* Morph)	.04	.01, .07	.58
N primes	264		
N participants	150		
N targets	88		
N datapoints	5019		

P-values below an alpha level of 0.05 are boldface.

Table 5 – Experiment 1: plural model summary.

	Log-transformed RT		
	Betas	CI	*p*-Values
Fixed effects			
(Intercept)	10.02	9.99, 10.06	**<.001**
Distance			
0 *vs* 1 interveners	−.02	−.04, .01	.225
1 *vs* 5 interveners	.03	.01, .06	**.015**
Prime–target relationship			
Morphological *vs* Baseline	−.17	−.20, −.14	**<.001**
Repetition *vs* Morphological	−.12	−.15, −.10	**<.001**
Stem frequency	−.05	−.07, −.03	**<.001**
Target duration	.09	.07, .10	**<.001**
ISI	.01	.00, .02	**.014**
Target phonological neighborhood	0	−.01, .02	.700
Log-transformed previous RT	.07	.06, .08	**<.001**
Transitional probability of plural suffix	.03	.01, .05	**.002**
Trial number	−.05	−.05, −.04	**<.001**
Previous trial accuracy	.03	.01, .06	**.039**
Previous trial lexicality	0	−.01, .02	.908
Participant gender	.02	−.02, .07	.370
Distance (0 *vs* 1) × P–t rel. (Morph *vs* Baseline)	.05	.02, .09	**.007**
Distance (1 *vs* 5) × P–t rel. (Morph *vs* Baseline)	−.01	−.04, .03	.705
Distance (0 *vs* 1) × P–t rel. (Rep *vs* Morph)	.04	.01, .07	**.038**
Distance (1 *vs* 5) × P–t rel. (Rep *vs* Morph)	.08	.05, .12	**<.001**
N primes	264		
N participants	150		
N targets	88		
N datapoints	4888		

P-values below an alpha level of 0.05 are boldface.

To summarize, we find significant Rep and Morph priming effects. The degree of facilitation was greater for the Rep than for the Morph condition at distances of 0 and 1 intervening item, and only marginally greater in the singular data when 5 items intervened.

3.2.2. *Phonological sub-experiment*

As in the stem sub-experiment, we constructed separate models for the substring and superstring targets summarized in Tables 7 and 8 respectively. In Table 6, we report the

Table 6 – Summary of transformed betas in the phonological sub-experiment of Experiment 1.

Target condition	Prime condition	Number of interveners		
		0	1	5
Substring targets	Phonological	1.27	.65	−2.27
	Repetition	20.86	14.24	10.23
Superstring targets	Phonological	6.44	1.31	3.94
	Repetition	11.35	9.82	3.94

Phonological = % faster than Baseline; Repetition = % faster than Phonological.

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Table 7 – Experiment 1: substring model summary.

	Log-transformed RT		
	Betas	CI	*p*-Values
Fixed effects			
(Intercept)	9.99	9.94, 10.05	**<.001**
Distance			
0 *vs* 1 interveners	.01	−.05, .07	.726
1 *vs* 5 interveners	.03	−.02, .07	.280
Prime–target relationship			
Phonological *vs* Baseline	−.02	−.06, .03	.509
Repetition *vs* Phonological	−.34	−.38, −.29	**<.001**
Substring frequency	−.02	−.06, .02	.460
Target duration	.09	.06, .12	**<.001**
ISI	0	−.01, .01	.845
Target phonological neighborhood	0	−.03, .03	.067
Log-transformed previous RT	.09	.08, .10	**<.001**
Transitional probability of final segment	−.01	−.05, .04	.845
Trial number	−.01	−.02, .00	.067
Previous trial accuracy	.07	.02, .12	**.014**
Previous trial lexicality	0	−.03, .04	.903
Participant gender	.04	−.00, .09	.113
Distance (0 *vs* 1) × P–t rel. (Phon *vs* Baseline)	.01	−.05, .07	.808
Distance (1 *vs* 5) × P–t rel. (Phon *vs* Baseline)	.04	−.02, .11	.293
Distance (0 *vs* 1) × P–t rel. (Rep *vs* Phon)	.12	.05, .18	**.003**
Distance (1 *vs* 5) × P–t rel. (Rep *vs* Phon)	.07	.00, .13	.091
N participants	150		
N primes	105		
N targets	35		
N datapoints	1835		

P-values below an alpha level of 0.05 are boldface.

Table 8 – Experiment 1: superstring model summary.

	Log-transformed RT		
	Betas	CI	*p*-Values
Fixed effects			
(Intercept)	9.95	9.90, 10.00	**<.001**
Distance			
0 *vs* 1 interveners	.02	−.03, .07	.516
1 *vs* 5 interveners	.03	−.01, .06	.279
Prime–target relationship			
Phonological *vs* Baseline	−.10	−.14, −.05	**<.001**
Repetition *vs* Phonological	−.17	−.22, −.13	**<.001**
Substring frequency	−.02	−.05, .01	.298
Target duration	.12	.10, .15	**<.001**
ISI	.01	.01, .02	**.011**
Target phonological neighborhood	.03	.01, .06	**.016**
Log-transformed previous RT	.06	.05, .07	**<.001**
Transitional probability of final segment	.02	−.01, .05	.291
Trial number	−.02	−.03, −.01	**<.001**
Previous trial accuracy	.05	−.03, −.01	**.034**
Previous trial lexicality	.04	.01, .08	**.048**
Participant gender	.03	−.01, .08	.218
Distance (0 *vs* 1) × P–t rel. (Phon *vs* Baseline)	.08	.02, .13	**.019**
Distance (1 *vs* 5) × P–t rel. (Phon *vs* Baseline)	−.04	−.09, .02	.242
Distance (0 *vs* 1) × P–t rel. (Rep *vs* Phon)	.02	−.03, .08	.445
Distance (1 *vs* 5) × P–t rel. (Rep *vs* Phon)	.09	.03, .15	**.013**
N participants	150		
N primes	105		
N targets	35		
N datapoints	2029		

P-values below an alpha level of 0.05 are boldface.

percentage increase in millisecond RT from the interpretation of the full substring model and full superstring model coefficients. Fig. 4 shows mean facilitation for Phon and Rep conditions for each target type. Significant main effects of only the rep versus phon condition were consistently found.

In the substring model, at 0 interveners there was no significant difference between Phon primes (*grape* → *gray*) versus Baseline primes ($\beta = -.02$, $p = .509$) whereas targets preceded by Rep primes were responded to significantly faster than those by Phon primes ($\beta = -.34$, $p < .001$). Separate models for each distance indicate that only the comparison between Rep versus Phon conditions was significantly different, and this was consistent across all distances (0 interveners: $\beta = -.35$, $p < .001$; 1 intervener: $\beta = -.204$, $p < .001$; 5 interveners: $\beta = -.149$, $p < .001$).

In the superstring model, targets preceded by the same word in the Rep condition were responded to significantly faster than targets in the Phon condition ($\beta = -.17$, $p < .001$). Unlike the substring model, Phon priming was significantly faster than Baseline at immediate distances ($\beta = -.096$, $p < .001$). Separate models for each distance indicate that Rep versus Phon conditions are significantly different at all distances (0 interveners: $\beta = -.17$, $p < .001$; 1 intervener: $\beta = -.194$, $p < .001$; 5 interveners: $\beta = -.083$, $p = .005$). The contrast between Phon versus Baseline was only significantly different at 0 and marginally different at 5 interveners (0 interveners: $\beta = -.09$, $p = .002$; 1 intervener: $\beta = .024$, $p = .411$; 5 interveners: $\beta = -.05$, $p = .078$).

As for interactions between distance and prime condition in the substring model, one interaction term was statistically significant. The slopes from 0 to 1 intervener were different between the Rep condition and the Phon condition ($\beta = .12$, $p = .003$). In the superstring model, two interactions between distance and prime condition were significant. The slopes from 0 to 1 intervener were different between the Phon condition and the Baseline condition ($\beta = .077$, $p = .019$) and the slopes from 1 to 5 interveners were different between the Rep condition and the Phon condition ($\beta = .091$, $p = .013$).

As in the stem sub-experiment, we also constructed a large model to investigate whether target type interacted with prime condition and/or the distance manipulations. In this model, there were no significant three-way interactions between target condition, distance and prime condition, which suggests that – even though different patterns are observed in the separate models – these interaction effects for the two target types are not themselves significantly different from one another.

In sum, we find significant effects of Rep priming with the same pattern of attenuation previously found. Notably, we find no consistent pattern of phonological priming. Only in the superstring model do we find evidence of phonological priming at immediate distances.

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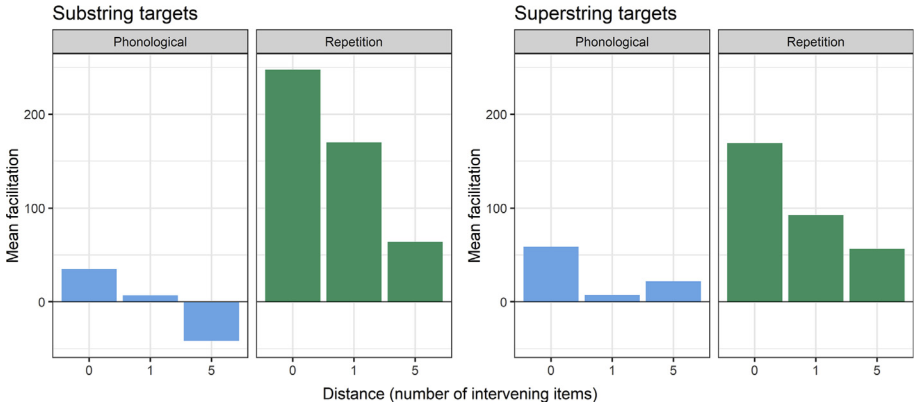

Fig. 4 – Facilitation plots for each target type in the phonological sub-experiment of Experiment 1 (calculated as raw mean BASELINE RT − raw mean RT for each Distance × Prime–target relationship condition).

3.2.3. *Comparisons between stem and phonological sub-experiments*

We constructed a model to directly compare MORPH priming in the Stem sub-experiment and PHON priming in the Phonological sub-experiment. For this model, we excluded the REP condition. As such, a BASELINE prime condition and a related prime condition remained. Depending on the sub-experiment, the related prime condition corresponds to a MORPH or PHON prime. The model examines the interaction between sub-experiment (Stem *vs* Phonological), prime condition (BASELINE *vs* related), target condition (Plural/Superstring *vs* Singular/Substring), and distance (0, 1, and 5 interveners). The control fixed effects included in previous models were also included as well as random intercepts for prime, target, and participant. Apart from distance, which was dummy coded, all other categorical predictors were sum coded. We focus on the interaction between sub-experiment and prime condition, as this directly compares any facilitation due to MORPH priming with any facilitation due to PHON priming. This interaction is significant when the reference level was set to 0 interveners ($\beta = -.146$, $p < .001$), 1 intervener ($\beta = -.123$, $p < .001$), and 5 interveners ($\beta = -.080$, $p < .001$). As such, the model indicates that facilitation due to MORPH priming is greater than facilitation due to PHON priming at all distances. Furthermore, when the reference level for distance is set to 0 interveners, there is a three-way interaction between Sub-Experiment, Prime condition, and Target condition ($\beta = .147$, $p < .001$) which indicates that the difference in facilitation between Stem and Phonological sub-experiments is smaller for Plural/Superstring targets compared to Singular/Substring targets. This is due to the short-lived source of phonological facilitation present for Superstring (*gray* → *grape*) but not Substring targets (*grape* → *gray*) in the Phonological sub-experiment. This three-way interaction did not reach significance when the reference level for Distance was set to 1 or 5 interveners.

This model is consistent with the idea that facilitation in the MORPH condition cannot be attributed to phonological relatedness. Facilitation due to MORPH priming is greater than facilitation due to PHON priming. However, we note that Experiment 1 and Experiment 2 were not optimally designed for direct statistical comparisons across sub-experiments. Although we tried to match PHON and MORPH targets in frequency and neighborhood density, targets are not tightly controlled across sub-experiments (see discussion in Section 3). Furthermore, there is approximately triple the data in the Stem sub-experiment than the Phonological sub-experiment. Although mixed effects models can in principle eliminate some of this extraneous variance, there is reason to be cautious in interpreting our models which compare across sub-experiments.

3.3. *Discussion*

In the stem sub-experiment, for both singular and plural targets, the REP condition consistently produced greater facilitation than the MORPH condition. Singular primes produced greater facilitation for singular targets than plural primes, whereas plural primes produced greater facilitation for plural targets compared to singular primes.

The distance manipulation shows a pattern in which both $\mathcal{F}_{\text{rep}}$ and $\mathcal{F}_{\text{morph}}$ decrease as the number of interveners between prime and target increases, as expected. Moreover, the differences between MORPH and REP priming decrease as the number of interveners increases: MORPH and REP priming effects are significantly different at earlier distances, but arguably not with 5 interveners. More precisely, at 5 interveners, the MORPH/REP contrast is marginally significant with singular targets but not with plural targets. This result suggests a potential convergence in facilitation between the two conditions, such that effects of inflectional morphology on lexical representations have converged by 5 interveners. While it is possible that a lack of statistical power is responsible for small differences between REP and MORPH not being detectable at this distance, we believe that the results show a pattern of convergence; as far as this goes, Kouider and Dupoux's (2009) show REP/MORPH being identical beyond a certain number of interveners as well.

The implications of these findings are examined in detail in the General discussion. For the immediate concerns of Experiment 1, it is important to stress that the effects observed in the MORPH condition are not driven by phonological overlap. This point is established by the phonological sub-experiment.

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There, we find evidence for a directional asymmetry in phonological priming effects. For superstring targets (*grape*), there is a significant effect of phonological priming at 0 and marginally significant at 5 interveners (*gray* → *grape*) whereas no such effect is found for substring targets (*grape* → *gray*). This is consistent with core aspects of the Cohort Model (Marslen-Wilson & Welsh, 1978), according to which there is a concurrently activated cohort of lexical items consistent with the phonological input which are inhibited once inconsistent phonological information arrives. In processing *gray*, *grape* is a member of the activated cohort. In processing *grape*, *gray* has been inhibited when the final segment /p/ is processed (as /p/ is inconsistent with *gray*).

In a model that directly compares Stem and Phonological sub-experiments, facilitation due to Morph priming was greater than facilitation due to Phon priming at all distances. Turning to the time-course of priming effects, while Morph priming persists across 0, 1, and 5 interveners, Phon priming seems to be restricted to an immediate distance. In addition, while the phonological experiment shows an asymmetry between substring and superstring targets at immediate presentation, we do not find a similar directional asymmetry for Morph priming.

Furthermore, we note that it is possible to rule out a potential concern about lexical decisions to embedded words (i.e., both *frog* in *frogs* and *gray* in *grape*), namely that participants may be responding to the embedded word rather than the longer word. Our results do not indicate that this is a problem. First, if responses to embedded words were taking place throughout the experiment, we would expect no asymmetries between the Morph and Phon conditions. Second, within the stem experiment, a plural prime is a better prime for a plural target whereas a singular prime is a better prime for singular targets. This pattern would not be anticipated if participants were simply responding to the embedded stems.

4. Experiment 2

Experiment 2 is both a direct replication of the results of the stem sub-experiment of Experiment 1 and an extension. The phonological sub-experiment of Experiment 1 was replaced with a sub-experiment examining the effects of semantic priming. It similarly contains two target types, but instead of being phonologically related as in Experiment 1 (i.e., *gray* and *grape*), they are semantically related (i.e., *beach* and *sand*). For expository purposes, these two target types are termed “Semantic A” and “Semantic B” in the discussion of the design, even though they will be examined together. As before, conditions were constructed by combining these two item types with an unrelated, baseline prime. The conditions of Experiment 2 are summarized below in Table 9.

In order to examine the patterns of priming-effect attenuation, we manipulated the distance between prime and target such that there were either 0, 1, or 5 intervening stimuli. Overall, there were again 18 conditions each for the stem and semantic sub-experiments, crossing Target condition (Singular *vs* Plural/SemanticA *vs* SemanticB) × Prime condition (Rep, Morph/Sem, *vs* Baseline) × Distance (0, 1, and 5 intervening items).

Table 9 – Prime and target conditions in the two sub-experiments of Experiment 2.

Sub-experiment	Prime condition		Target condition	
Stem	Baseline	*smoke*	Singular	*frog*
	Morphological	*frogs*		
	Repetition	*frog*		
	Baseline	*smoke*	Plural	*frogs*
	Morphological	*frog*		
	Repetition	*frogs*		
Semantic	Baseline	*ramp*	Semantic A	*beach*
	Semantic	*sand*		
	Repetition	*beach*		
	Baseline	*ramp*	Semantic B	*sand*
	Semantic	*beach*		
	Repetition	*sand*		

4.1. *Method*

4.1.1. *Stimuli*

The stimuli for the stem sub-experiment were identical to those in Experiment 1. For the semantic sub-experiment, 36 semantically related, monosyllabic pairs were chosen from a database of free association word norms (Nelson, McEvoy, & Schreiber, 2004). As such, at least 2 out of ≈150 subjects in a norming study had provided one word of the pair in free association with the other word, which constitutes “a relatively strong associate” (Nelson et al., 2004). All semantically related pairs had an LSA value of at least .3 [mean = .5, range = (.3, .85)]. These pairs were roughly equivalent to the stem sub-experiment words in frequency using the Lg10CD measure from SUBTLEX-US (Brysbaert & New, 2009, mean = 3.05) and in phonological neighborhood density using the relevant measure from the English Lexicon Project (Balota et al., 2007, mean = 17.85). Unrelated, baseline primes were chosen to be minimally semantically related [using LSA: mean = .074, range = (−-.04, .3)] to either of the semantically related members of a pair. These new stimuli were recorded in the same manner as in Experiment 1.

4.1.2. *Participants*

Participants for Experiment 2 were recruited from the online experiment hosting site Prolific (https://prolific.ac/). In return for payments of £2.10, 72 participants provided informed consent and completed the study in the spring of 2018.

4.1.3. *Procedure*

The task and implementation using the experimental presentation software Ibex were virtually identical to that of Experiment 1.

4.2. *Results*

Of the 72 participants, 12 were removed due to a large number of inaccurate responses (<70% overall accuracy) or abnormally slow experimental presentation (average delays of >20 msec). Furthermore, three items were removed due to overall

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accuracy below 50%. From the remaining 60 participants, trials were removed if either the prime or the target were inaccurate. After fillers were removed, trials with RTs less than 300 msec or greater than 2500 msec were deemed unreasonable and removed, resulting in the removal of 4.8% of the data. An additional 4.6% of the data was removed following the same minimal trimming procedures of Baayen and Milin (2010), discussed in Section 3.2. This number is again much less than the maximum set out by Ratcliff (1993), although it is larger than the sample experiments of Baayen and Milin (2010) by less than two percentage points. The increase in data removed in Experiment 2 compared to the equivalent 1.4% of Experiment 1 may be due to the fact that the participants of Experiment 2 were recruited from a different participant pool than Experiment 1 ("Prolific" is open to the general public while in Experiment 2 participants were recruited from a university community). Crucially however, the same procedures were followed in both experiments, and therefore we do not expect any bias to be introduced from the minimal a-priori trimming we performed.

Similar to Experiment 1, the analysis of this experiment focuses only on the RT data. We initially discuss some general trends in the accuracy data here however. Overall, singular and plural targets were each responded to with 94% accuracy. In Table 10, we see the corresponding error rates broken down by condition. Again, targets in the Rep and Morph conditions were responded to more accurately than the Baseline condition targets, as predicted by the literature on Rep and Morph priming. For the semantic sub-experiment, overall accuracy was quite high, with Semantic A and Semantic B stimuli responded to with 97% and 95% accuracy. All of the subsequent models were implemented following the same procedures outlined in Section 3.2. Fig. 5 shows predicted log-transformed RTs from separate models fitted to each Target Condition (models discussed in detail below). For each Target Condition, predicted log-transformed RT is plotted for each Prime Condition at each Distance.

4.2.1. *Stem sub-experiment*

We constructed separate models for the singular and plural targets in the same manner as that of Experiment 1. These models are summarized in Tables 12 and 13 respectively. In Table 11, we report the percentage increase in RT from the interpretation of the full singular model and full plural model coefficients. Fig. 6 shows mean facilitation for morph and rep conditions for each target type.

Significant main effects of the two prime condition contrasts were again found in both singular and plural models, replicating the results of Experiment 1. Starting with the singular model, the results indicate that, at immediate distances, Morph was significantly faster than Baseline ($\beta = -.23$, $p < .001$) and that Rep was significantly faster than Morph ($\beta = -.08$, $p < .001$). In separate models, we evaluated whether this pattern held at distances of 1 and 5 intervening items. Similar to Experiment 1 with 1 intervener, Morph was significantly faster than Baseline ($\beta = -.14$, $p < .001$) and Rep was significantly faster than Morph ($\beta = -.05$, $p = .027$). The Morph condition was also significantly faster than the Baseline condition at 5 interveners ($\beta = -.13$, $p < .001$), however there was no statistically significant difference between Morph and Rep conditions at this distance ($\beta = .01$, $p = .67$), unlike the results from the singular data in Experiment 1. This indicates that Morph and Rep priming did converge at 5 interveners in this particular model.

Turning to the model of the plural targets, the results indicate that, at immediate distances, Morph was significantly faster than Baseline ($\beta = -.23$, $p < .001$) and Rep was significantly faster than Morph ($\beta = -.04$, $p = .05$). Separate models examining the effect of distance indicated that, at 1 intervener, the Morph condition was significantly faster than the Baseline condition ($\beta = -.13$, $p < .001$) and the Rep condition was significantly faster than the Morph condition ($\beta = -.10$, $p < .001$). At 5 interveners, similar to the plural results from Experiment 1 and the singular model from Experiment 2, the Morph condition was significantly faster than the Baseline condition ($\beta = -.12$, $p < .001$) but the comparison between Rep and Morph was not significant ($\beta = .02$, $p = .43$).

We again found significant interaction effects between the distance and prime condition contrasts in both models. For singular and plural targets, Baseline and Morph conditions at 0 versus 1 intervening items exhibited significantly different slopes (Singular: $\beta = .08$, $p = .003$; Plural: $\beta = .08$, $p = .004$) whereas no such interaction was found at 1 versus 5 intervening items (Singular: $\beta = .01$, $p = .617$; Plural: $\beta = .02$, $p = .426$). These effects again indicate the stability of responses in the Baseline condition between 0 and 1 interveners and the diminishing effect over time for the Morph and Rep conditions. In the plural model, the interaction between Morph and Rep conditions was marginally significant at 0 versus 1 ($\beta = -.05$, $p = .081$) and significant at 1 versus 5 intervening items ($\beta = .08$, $p = .006$), indicating a different rate of priming reduction between the two conditions at these distances.

In the combined model including both target types, we found a significant main effect of target condition ($\beta = .1$, $p = .001$) indicating that responses to plural targets were 7.2% slower than responses to singular targets. In conclusion, we find significant Rep and Morph priming effects. The degree of facilitation was greater for the Rep than for the Morph condition at distances of 0 and 1, but not for 5, intervening items.

Table 10 – Target error rates for Experiment 2.

Sub-experiment	Prime condition	Target condition	Target error rate (%)
Stem	Baseline	Singular	8.3
		Plural	8.7
	Morphological	Singular	4.6
		Plural	4.8
	Repetition	Singular	5.0
		Plural	5.5
Semantic	Baseline	Semantic A	3.6
		Semantic B	5.6
	Semantic	Semantic A	2.5
		Semantic B	5.3
	Repetition	Semantic A	3.6
		Semantic B	4.2

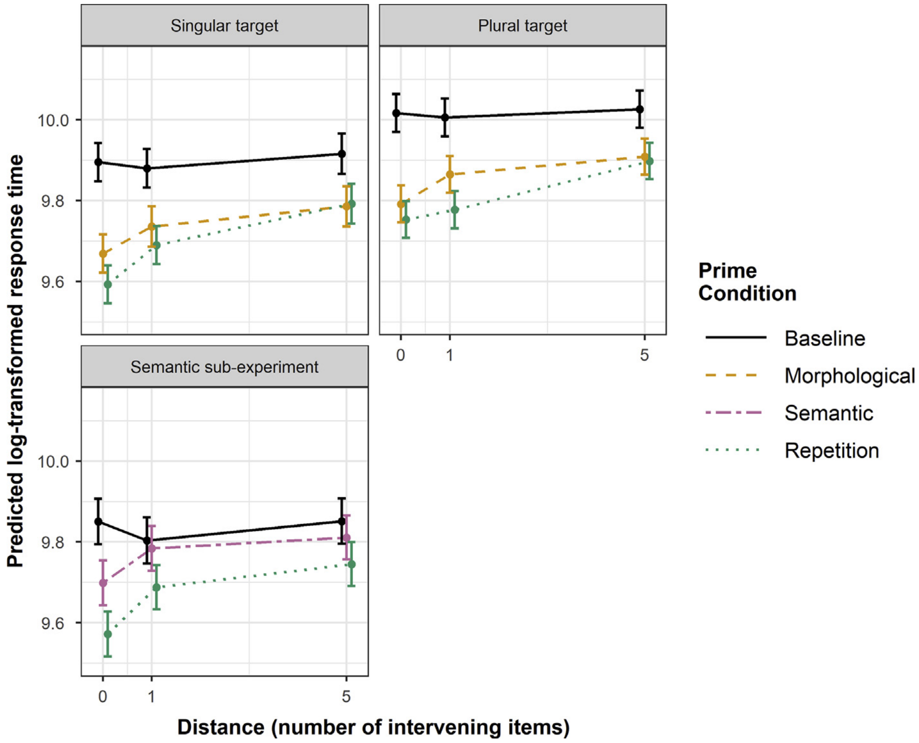

Fig. 5 – Predicted log-transformed RTs from the models for each target type in Experiment 2.

4.2.2. *Semantic sub-experiment*

For the semantic sub-experiment, we constructed a combined model for both target types, as we have no prior hypothesis concerning any difference between targets in the "Semantic A" and "Semantic B" lists. The goal of this sub-experiment was to compare the facilitation pattern of Sem priming with that of Morph priming. In Table 15, we summarize the model for semantic targets and in Table 14, we report the percentage increase in millisecond RT from the interpretation of the coefficients from the semantic model. Fig.7 shows mean facilitation for sem and rep conditions.

Overall, in the semantic model, we find strong evidence for an early effect of semantic priming that dissipates by 1 intervener. We find, at 0 interveners, that Sem targets were responded to significantly faster than Baseline targets ($\beta = -.15$, $p < .001$). Separate models for each distance indicate that the Sem versus Baseline comparison was only significant at 0 interveners, with non-significant results at distances of 1 ($\beta = -.03$, $p = .202$) and marginal results at 5 interveners ($\beta = -.04$, $p = .073$). Comparing the Rep and Sem conditions, we find that Rep was significantly faster at all distances (0 interveners: $\beta = -.13$, $p < .001$; 1 intervener: $\beta = -.09$, $p < .001$; 5 interveners: $\beta = -.06$, $p = .003$).

Table 11 – Summary of transformed betas from the stem sub-experiment of Experiment 2.

Target condition	Prime condition	Number of interveners		
		0	1	5
Singular targets	Morphological	14.52	9.49	8.62
	Repetition	5.12	3.16	−.44
Plural targets	Morphological	14.44	9.28	7.81
	Repetition	2.64	5.92	.73

Morphological = % faster than Baseline; Repetition = % faster than Morphological.

As for interactions between distance and prime condition in the semantic model, one interaction term was statistically significant. The slopes from 0 to 1 intervener were different between the Sem condition and the Baseline condition ($\beta = .13$, $p < .001$). This indicates that there was a significant decay pattern from 0 to 1 intervener in the Sem and Rep conditions. In conclusion, we find significant effects of Rep priming with the same pattern of attenuation previously found. Notably, we find only early semantic priming; once one item intervenes between prime and target, semantic priming dissipates.

4.2.3. *Comparisons between stem and semantic sub-experiments*

Following the same modelling procedure as for Experiment 1, we constructed a model to directly compare Morph priming in the Stem sub-experiment and Sem priming in the Semantic sub-experiment. This model examines the interaction between sub-experiment (Stem *vs* Semantic), prime condition (Baseline *vs* related), and distance (0, 1, and 5 interveners). We focus on the interaction between sub-experiment and prime condition, as this directly compares any facilitation due to Morph priming with any facilitation due to Sem priming. We examined this sub-experiment and prime condition

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Table 12 – Experiment 2: singular model summary.

	Log-transformed RT		
	Betas	CI	*p*-Values
Fixed effects			
(Intercept)	9.89	9.84, 9.95	**<.001**
Distance			
0 *vs* 1 interveners	−.02	−.06, .03	.46
1 *vs* 5 interveners	.04	−.01, .08	**.097**
Prime–target relationship			
Morphological *vs* Baseline	−.23	−.26, −.19	**<.001**
Repetition *vs* Morphological	−.08	−.11, −.04	**<.001**
Stem frequency	−.02	−.04, .00	.058
Target duration	.08	.06, .10	**<.001**
ISI	0	−.01, .01	.442
Target phonological neighborhood	.01	−.01, .03	.325
Log-transformed previous RT	.04	.03, .05	**<.001**
Transitional probability of plural suffix	.01	−.00, .03	.14
Trial number	−.02	−.03, −.01	**<.001**
Previous trial accuracy	0	−.04, .04	.91
Previous trial lexicality	0	−.03, .03	.945
Participant gender	.02	−.05, .10	.54
Distance (0 *vs* 1) × P–t rel. (Morph *vs* Baseline)	.08	.03, .14	**.003**
Distance (1 *vs* 5) × P–t rel. (Morph *vs* Baseline)	.01	−.04, .07	.617
Distance (0 *vs* 1) × P–t rel. (Rep *vs* Morph)	.03	−.02, .08	.273
Distance (1 *vs* 5) × P–t rel. (Rep *vs* Morph)	.05	−.00, .11	.054
N primes	261		
N targets	87		
N participants	60		
N datapoints	1999		

P-values below an alpha level of 0.05 are boldface.

Table 13 – Experiment 2: plural model summary.

	Log-transformed RT		
	Betas	CI	*p*-Values
Fixed effects			
(Intercept)	9.99	9.94, 10.05	**<.001**
Distance			
0 *vs* 1 interveners	−.01	−.06, .03	.627
1 *vs* 5 interveners	.02	−.02, .06	.345
Prime–target relationship			
Morphological *vs* Baseline	−.23	−.27, −.18	**<.001**
Repetition *vs* Morphological	−.04	−.08, −.00	**.05**
Stem frequency	−.02	−.04, −.00	**.025**
Target duration	.1	.08, .12	**<.001**
ISI	0	−.01, .01	.606
Target phonological neighborhood	0	−.01, .02	.637
Log-transformed previous RT	.05	.04, .06	**<.001**
Transitional probability of plural suffix	.02	.00, .04	**.021**
Trial number	−.03	−.04, −.03	**<.001**
Previous trial accuracy	.04	−.00, .09	.058
Previous trial lexicality	.02	−.01, .04	.205
Participant gender	.03	−.04, .09	.408
Distance (0 *vs* 1) × P–t rel. (Morph *vs* Baseline)	.08	.03, .14	**.004**
Distance (1 *vs* 5) × P–t rel. (Morph *vs* Baseline)	.02	−.03, .08	.426
Distance (0 *vs* 1) × P–t rel. (Rep *vs* Morph)	−.05	−.11, .01	.081
Distance (1 *vs* 5) × P–t rel. (Rep *vs* Morph)	.08	.02, .13	**.006**
N primes	261		
N targets	87		
N participants	60		
N datapoints	1997		

P-values below an alpha level of 0.05 are boldface.

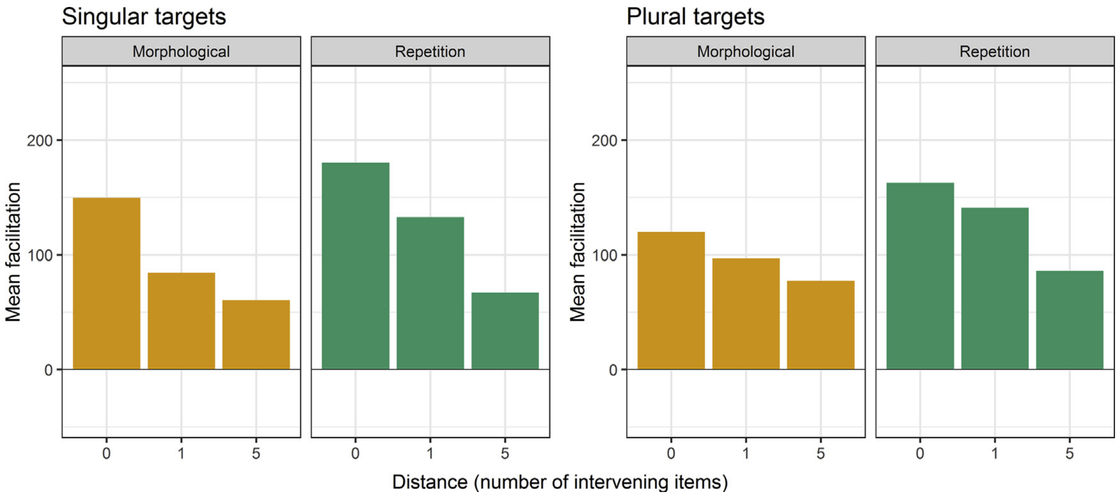

Fig. 6 – Facilitation plots for each target type in the stem sub-experiment of Experiment 2 (calculated as raw mean Baseline RT – raw mean RT for each Distance × Prime–target relationship condition).

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Table 14 – Summary of transformed betas from the semantic sub-experiment of Experiment 2.

Target condition	Prime condition	Number of interveners		
		0	1	5
Semantic targets	Semantic	10.01	1.36	2.79
	Repetition	8.4	6.44	4.44

Semantic = % faster than Baseline; Repetition = % faster than Semantic.

interaction in the model with the reference level for Distance set to 0 interveners ($\beta = -.053$, $p = .035$), 1 intervener ($\beta = -.116$, $p = .001$) and 5 interveners ($\beta = -.089$, $p = .001$). At all distances, this interaction is significant and indicates greater facilitation due to Morph priming compared to Sem priming.

This model is consistent with the idea that facilitation in the Morph condition cannot be attributed to semantic relatedness, in that it provides a direct comparison showing a significant difference between Morph and Sem priming. However, as discussed in Section 3.2.3, there are reasons to exercise caution in interpretation of these direct comparisons.

4.3. *Discussion*

In the stem sub-experiment of Experiment 2, we find a direct replication of the results from Experiment 1. The Rep condition consistently produced greater facilitation than the Morph condition at early distances, indicating that singular primes produced greater facilitation for singular targets than plural ones, and vice versa. The distance manipulation verified the pattern described earlier in Section 3.3 that both $\mathcal{F}_{\mathrm{rep}}$ and $\mathcal{F}_{\mathrm{morph}}$ decrease as the number of interveners between prime and target increases.

Table 15 – Experiment 2: semantic model summary.

	Log-transformed RT		
	Betas	CI	*p*-Values
Fixed effects			
(Intercept)	9.84	9.78, 9.90	**<.001**
Distance			
0 *vs* 1 interveners	−.05	−.10, .00	.064
1 *vs* 5 interveners	.05	.01, .09	**.022**
Prime–target relationship			
Semantic *vs* Baseline	−.15	−.19, −.11	**<.001**
Repetition *vs* Semantic	−.13	−.17, −.09	**<.001**
ISI	−.01	−.02, .00	.294
Log-transformed previous RT	.06	.05, .07	**<.001**
Target frequency	.01	−.02, .04	.46
Trial number	0	−.01, .01	.91
Previous trial accuracy	.02	−.02, .07	.282
Previous trial lexicality	.01	−.02, .04	.639
Participant gender	.03	−.05, .11	.432
Distance (0 *vs* 1) × P–t rel. (Sem *vs* Baseline)	.13	.08, .19	**<.001**
Distance (1 *vs* 5) × P–t rel. (Sem *vs* Baseline)	−.02	−.08, .04	.47
Distance (0 *vs* 1) × P–t rel. (Rep *vs* Sem)	.03	−.03, .09	.284
Distance (1 *vs* 5) × P–t rel. (Rep *vs* Sem)	.03	−.03, .09	.291
N primes	108		
N targets	72		
N participants	60		
N datapoints	1743		

P-values below an alpha level of 0.05 are boldface.

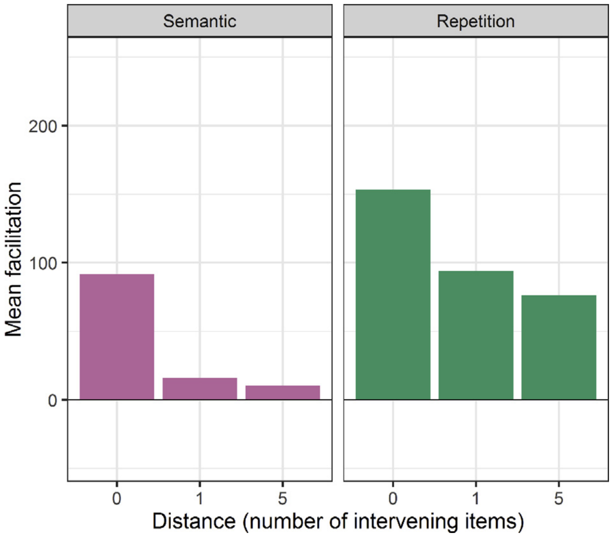

Fig. 7 – Facilitation plot for the semantic sub-experiment of Experiment 2 (calculated as raw mean Baseline RT − raw mean RT for each Distance × Prime–target relationship condition).

Besides being able to have more confidence in our main findings, the stem sub-experiment gave us two more tests of the difference between $\mathcal{F}_{\mathrm{rep}}$ and $\mathcal{F}_{\mathrm{morph}}$ at 5 interveners. In Experiment 2, both the singular and plural targets exhibited patterns whereby Morph and Rep priming differed significantly from each other at 0 and 1 intervener distances, but not at 5 intervener distances. Combined with Experiment 1, we find that, out of four tests of Rep and Morph differences at a distance of 5 interveners, only one test indicated a marginally significant difference. We take this result to implicate a convergence of $\mathcal{F}_{\mathrm{rep}}$ and $\mathcal{F}_{\mathrm{morph}}$ by 5 interveners. Further work is of course needed to determine a more precise time-course of this convergence.

The main contribution of Experiment 2 is the conclusion that the effects in the Morph condition are not driven by semantic overlap. In a model that directly compares Stem and Semantic sub-experiments, facilitation due to Morph priming was greater than facilitation due to Sem priming at all distances. Examining the time-course of the priming effects, Morph priming persists across 0, 1, and 5 intervening items. In contrast, Sem priming dissipates more rapidly: the semantic sub-experiment of Experiment 2 shows an effect of semantic overlap at immediate distances. By 1 intervener, this effect disappears. Therefore, we conclude that semantic overlap is not the source of the longer lasting priming effects observed in the Morph conditions in both experiments.

5. General discussion

5.1. *Implications for decompositional theories*

As we noted in our introduction, the specific predictions of decompositional theories for Morph and Rep priming depend on

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a number of details. Considering activation of a stem alone, it might be predicted that Morph and Rep should yield identical priming facilitation, since the stem is activated in the prime and target in each of these conditions. When we consider that other hypothesized processing stages, decomposition and recombination in particular, might have effects that are detectable in priming, the possibility arises that differences between Morph and Rep might be found. This is in fact precisely what our experiments reveal: $\mathcal{F}_{\text{morph}}$ is consistently less than $\mathcal{F}_{\text{rep}}$, with this difference, moreover, appearing to decrease as the number of interveners between prime and target increases.

One possibility is that M/R differences stem from the decomposition stage. If decomposition has a cost that reduces priming facilitation, then Morph priming in *frogs* → *frog* or *frog* → *frogs* is expected to be less than Rep, since the Morph condition pairs each contain one additional morpheme, triggering the decomposition stage on one member of the pair. However, this hypothesis predicts that with plural targets, the Rep condition *frogs* → *frogs* should show less facilitation than the Morph condition *frog* → *frogs*, since the Rep pair has additional morphemes on both members of the pair, which trigger the decomposition stage, whereas for the Morph pair, only one member has the additional morpheme. But this is not what the results show: plural targets show significantly more facilitation with plural primes than with singular primes. This makes the decomposition-based explanation inadequate.

As can be seen from the discussion above, the plural target condition plays a crucial role in ruling out a decomposition-based explanation of M/R differences. With this in mind, a second possibility to consider is that it is the total number of shared morphemes that drives the amount of priming facilitation. In particular, we might hypothesize that facilitation in *frogs* → *frogs* is greater than that in either of the “mixed” Morph conditions, because the *frogs* pair shares two morphemes, whereas the Morph priming pairs share only the stem. This view can explain why facilitation with *frogs* → *frogs* is greater than in Morph *frog* → *frogs*. It does not, however, explain why Morph priming is less than Rep priming with *singular* targets. Both primes, *frogs* and *frog*, share one morpheme with the target *frog*. There should therefore be equivalent Morph and Rep facilitation with singular targets, but this is not what we find.

In our view, the best explanation for the main findings of our studies is centered on the *recombination* stage of lexical access. The core components of this explanation are that (i) when a complex word like *frogs* is processed, there is a recombination stage in which the stem and affix are put back together after being separated in the decomposition stage; (ii) something related to this recombination process can be facilitated (see below); and (iii) the locus of this facilitation is in episodic memory. There are at least two ways in which something related to the recombination process might be facilitated. One possibility is that the facilitation is due to an episodic memory representation of the recombined complex word. Another is that the process of recombination itself is facilitated. In our view, the former, representation-based view seems more likely; in particular, it is most consistent with a view of priming for which facilitation is due to activation of pieces rather than processes. Henceforth, when discussing facilitation related to the recombination process we make reference to this representation-based view.

The main findings are explained as follows. With plural targets, whose significance is highlighted above, plural primes produce greater facilitation than singular primes because there is (i) a boost in activation for the stem, and, in addition, (ii) facilitation of the representation created by the recombination process for the former, but not for the latter. With singular targets, singular primes (i.e., the Rep condition) produce more facilitation than plural primes (i.e., the Morph condition) due to episodic differences between prime and target. Specifically, in both *frog* → *frog* and *frogs* → *frog* the stem is activated; however, in the latter condition, the prime has an episodic difference from the target—the representation of the recombined complex word. It is well-established that episodic differences produce reductions in priming facilitation when prime and target are the same word; this is observed with font changes in the visual modality (*frog* → FROG; Graf & Ryan, 1990) and with talker switch in spoken word processing ($frog_{\text{Talker1}} \rightarrow frog_{\text{Talker2}}$; Goldinger, 1996), for example. Our proposal is that, while Morph pairs involve activation of the stem, they differ in an episodic property (the recombined complex word) and this difference results in less facilitation than in the Rep condition, where episodic properties of prime and target do not differ in this way.

In addition to providing an explanation for Rep/Morph differences, the hypothesis outlined above is also able to account for a further effect: the convergence of Rep and Morph as distance between prime and target increases. Facilitation due to episodic memory traces is expected to decay more rapidly than facilitation due to abstract activation of a stem, and this is precisely what the findings revealed by our distance manipulation show. That is, at increased distances, the episodic differences in the Morph conditions no longer have an effect; what is left is stem activation, with Morph and Rep showing similar levels of facilitation accordingly. As far as this part of the explanation goes, we note that Kouider and Dupoux (2009) offer a similar view of Morph and Rep, suggesting that morphology is, in effect, an “episodic” property of a complex word. The present explanation builds on their intuition, but posits a specific locus to the episodic effect in the representation created by the recombination process.

By way of comparison, we note that the effects that we have attributed to recombination could in principle be attributed to facilitation of the decomposition stage. For example, it is possible that in processing *frogs* the decomposition process that produces *frog* and -*s* could be facilitated in a way that produces priming within a limited time window (This view assumes that processes can be facilitated, which is contrary to what we have assumed above.). The same explanations offered above could be advanced with “decomposition” replacing “recombination”. This possibility is, in a sense, derived from our observations at the beginning of this section—if *frogs* and *frog* both involve activation of *frog*, then something else must be responsible for Morph/Rep differences, and the decomposition process could in principle be that factor.

While this is a possibility, we believe that there are reasons for preferring the recombination-based explanation. Our argument is based on evidence for how decomposition works with words with an “inflectional rhyme pattern” (IRP, e.g., Bozic, Tyler, Ives, Randall, & Marslen-Wilson, 2010). An IRP is a word-final coronal consonant (/d/, /t/, /s/, /z/) that shows agreement in voice between the final coronal consonant and the preceding segment. Decomposition effects for stems/pseudo-stems and affixes in IRP words are reported (e.g., Bozic et al., 2010; Post, Marslen-Wilson, Randall, & Tyler, 2008; Tyler, Randall, & Marslen-Wilson, 2002) suggesting that this is a fast and automatic process which occurs pre-lexically, before meanings are accessed. Given the speed and automaticity of this process, it is unlikely to be the locus of the effects that we report, as any speed-up due to facilitation from an episodic trace would be limited.

Finally, by way of concluding this part of the discussion, we note that our interpretation has been directly focused on implications for a specific set of decompositional models. Restricting attention in this way has a reciprocal motivation: on the one hand we believe that our results provide interesting insights into certain details of decompositional theories; and on the other, we believe that such theories provide a satisfying explanation for the overall patterns that we observed. As far as this goes, however, we wish to be perfectly clear that our findings do not **require** something like a recombination stage (or even a decompositional theory more generally). Very different-looking explanations might be offered in frameworks that differ in their fundamental assumptions from the type of decompositional theory examined here. For example, as pointed out to us by reviewers, a general notion of “relatedness expectation” might be able to account for our basic findings. Briefly, the idea is that upon hearing a word (either *frog* or *frogs*), the expectation is generated that the next occurrence of that word will be in the same form (singular or plural). When the expectation is met, there are processing savings, such that singular/singular and plural/plural priming are expected to show more facilitation than either of the “mixed” MORPH conditions. It remains to be seen how the predictions of this type of approach could distinguished from the recombination-based explanation that we have advanced above. One possibility is that differences might emerge when the effects of modality are taken into account; see Section 5.2.

In summary, while this paper concentrates on exploring the implications of MORPH-/REP contrasts for decompositional theories, we believe that our results have a broader relevance, and that they may have implications for other models of the mental lexicon. While a detailed examination of alternatives goes beyond the scope of the present discussion, it is our hope that both our results and the specific way in which we have looked at them will pave the way for future investigations of MORPH versus REP priming, in ways that might ultimately lead to fruitful comparisons across theoretical frameworks.

5.2. *Modality*

It was noted in our review of the literature that studies using overt (Fowler et al., 1985; Stanners et al., 1979) and masked (Forster et al., 1987) visual priming report no differences between MORPH and REP. This is unlike what we report here, leading to the question of why there might be differences in modality.

In part, it is important to be somewhat cautious about drawing any general conclusions. One reason for this is that the studies mentioned above report non-differences. These could be due to principled reasons, but they could also be driven by details of the experimental design or by a lack of statistical power. Another reason to be circumspect is that the findings to be compared are not aligned. For the reasons outlined above, using plural targets provides crucial insight into understanding what drives MORPH/REP differences. However, the visual studies that have been published to date do not employ plural targets. A full and direct comparison of findings across modality is therefore not possible.

In spite of these concerns, the issue of possible modality differences is an important one, and it is worth reflecting on what might produce them. The obvious place to begin, which coincides with the concerns of the next section, concerns the temporal unfolding of the speech signal that characterizes auditory processing. Whereas visual processing makes the entire word available from the beginning such that the processing system appears to make use of both the left and right side of the word simultaneously (Rastle et al., 2004), auditory processing involves an incremental speech signal. With suffixes in particular, this means that the element that is crucial to the MORPH condition is not available until the end of the word (or slightly earlier if co-articulatory cues signal its presence).

Taking this difference into consideration, the following two (non-mutually exclusive) possibilities may address why modality differences might be manifested in REP/MORPH comparisons.

The first is that decomposition and recombination are simply easier in the visual modality, owing to the presence of morphology from the beginning. It might be the case, then, that rapid visual decomposition (and recombination) is effectively at ceiling, such that there would be an episodic difference (due to the decomposition or recombination steps) between primes and targets in MORPH, but the consequences of this hypothetical difference for priming facilitation would be negligible.

A second possibility, which relates to the “expectation-based” explanation of our results touched on at the end of 5.1, is that the incremental arrival of the speech signal allows for expectations about the target (given a particular prime) to be manifested. This view offers different explanations for why singular targets and plural targets show less facilitation in MORPH than for REP. For singular targets, the idea is that plural *frogs* as a prime leads to the expectation that the target should be plural as well. Given this expectation, subjects are biased to wait longer with incoming *frog* before responding, producing reduced facilitation relative to *frog* primes, which do not generate the plural expectation. For plural targets, the explanation is essentially the one that we advanced in Section 5.1: with plural primes, both the stem and the recombination step are facilitated; with singular primes on the other hand, there is facilitation driven only by the stem's activation.

An important aspect of this approach, which also reiterates a point we made above about the incompleteness of the data required for a full comparison, is that it makes an interesting prediction about modality differences. MORPH and REP with singular targets are expected to differ in visual versus auditory presentation: $\mathcal{F}_{\text{morph}} < \mathcal{F}_{\text{rep}}$ should be found only in the

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auditory modality, because it is only there that subjects receive the input incrementally in a way that could produce an effect of expectation. On the other hand, MORPH and REP with plural targets are predicted to be different in both the auditory and visual modalities. Irrespective of modality, the prime *frogs* shares with the target *frogs* the recombination step in addition to the stem. It is thus predicted that $\mathcal{F}_{\text{morph}} < \mathcal{F}_{\text{rep}}$ in both modalities. Of course, if the advantages of recombination priming are negligible in visual processing, as we discussed above, the picture is less clear.

The question of what might be responsible for modality-driven differences in REP/MORPH comparisons must be central to subsequent work on lexical processing. For our purposes, we have reviewed here some possible takes on why differences might be found, in ways that connect with our proposals in Section 5.1. In the end, stronger conclusions will have to wait until key comparisons can be made across modalities in a study that uses both singular and plural targets, for the reasons that we have examined at length above.

5.3. *Morphology, phonological overlap, and cohorts*

The incremental nature of auditorily presented words plays an important role in understanding possible modality differences, even if our comments in that domain must remain speculative. At the same time, there are more definite implications in our findings when we look at incrementality in more detail, particularly as it concerns the notion of what words constitute *competitors* for lexical activation.

As highlighted in work by Balling and Baayen (2008, 2012), models of word-recognition differ in significant ways with respect to their treatment of morphologically related words. For example, the definition of the *Uniqueness Point* in early work (Marslen-Wilson, 1984; Marslen-Wilson & Welsh, 1978) excludes words with suffixes and compounds from consideration; effectively, this means that *frog* is not in the cohort of competitors competing for activation when *frogs* is processed. On the other hand, the Shortlist B model proposed by Norris and McQueen (2008) [the predictions of which are a main focus of Balling and Baayen (2012)] treats morphologically related words as competitors, a consequence of the model adopting “Full Listing”.

The findings reported here provide evidence for the view that morphologically related forms are not competing in a cohort sense. The key observations derive from the phonological sub-experiment in Experiment 1, which shows markedly different results for substring/superstring pairs that are morphologically unrelated (*gray/grape*) when compared to pairs with the plural affix. This difference is particularly striking in that, as strings (i.e., purely in terms of sound representations), the primes and targets *grape/gray* and *frogs/frog* are remarkably similar; only one phoneme distinguishes the primes from the targets. The most transparent interpretation of this finding is, in our view, that morphologically related words do not compete with each other because they share activation of the same stem.

Overall, our findings here complement those of Balling and Baayen (2012), who center their arguments on the identification of two “uniqueness points” within complex words, one associated with the stem, and one with the affix. We note by way of conclusion that while both our results and theirs suggest that morphologically related words do not compete with each other, the materials employed in our studies differ in phonological and syntactico-semantic ways. For the former, Balling and Baayen (2012) use phonologically heavier suffixes (syllabic and disyllabic); the size of these affixes contrasts sharply with the -*s* that is used here. For semantics, the plural -*s* used here is a typical inflectional morpheme, and, as such, shows relatively limited interactions with the lexical semantics of the stem. On the other hand, Balling and Baayen's suffix materials consist of derivational morphemes, which (typically) have more robust individual meanings, meanings that potentially interact with that of the stem and can also define (or change) syntactic category.

6. Conclusion

In this paper, we investigate the nature of auditory priming facilitation due to morphological overlap. We do so by directly comparing the priming facilitation occurring between pairs of primes and targets which share only the stem (and differ according to the presence/absence of the plural morpheme -/z/) with both repetition and unrelated, baseline priming. By including both singular and plural targets, we are able to obtain a more complete picture of the effect of morphology on lexical processing relative to prior investigations, which have employed only singular targets.

Compared to the baseline condition, we find consistent priming in both morphological and repetition conditions at each of the three distances we examined. Differences between morphological and repetition facilitation are found reliably at an immediate distance and when one item intervenes between prime and target. At our longest distance of five items intervening between prime and target, the results indicate that morphological and repetition priming converge.

These results, which our two experiments show cannot be reduced to either phonological or semantic overlap respectively, are interpreted through the lens of a decompositional model of morphological processing. Our interpretation crucially hinges on two factors: the long-term activation of an abstract stem, and the priming of the output of the recombination process of lexical access in short-term, episodic memory. Plural–plural pairs exhibit more facilitation than singular–plural pairs due to the additional facilitation of the recombination process. Singular–singular pairs produce more facilitation than plural–singular due to the mismatch of episodic properties in the latter. In both cases, the effect of the episodically primed recombination stage of lexical access diminishes over time; explaining the rapid convergence observed by the time five items intervene between prime and target. This hypothesis makes an important step in tying together experimental studies of priming facilitation with theoretical models of the mental lexicon.

Declarations of interest

None.

Open practices

The study in this article earned an Open Data badge for transparent practices. Data for the study are available at https://osf.io/d6hms/.

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Appendix

Table A1 – Stem sub-experiment triplets 1–40 in Experiments 1 & 2.

	Singular	Freq.	Plural	Freq.	Baseline	Freq.
1	babe	3.00	babes	2.14	pole	2.60
2	barb	1.49	barbs	1.11	scout	2.61
3	barn	2.60	barns	1.34	inch	2.70
4	bay	2.79	bays	1.08	chin	2.67
5	brain	3.30	brains	3.01	pump	2.66
6	bride	2.81	brides	1.61	mug	2.42
7	bulb	2.17	bulbs	1.83	pin	2.74
8	card	3.32	cards	3.13	loaf	2.21
9	chain	2.87	chains	2.44	trash	2.91
10	cord	2.42	cords	1.87	grain	2.26
11	cove	1.91	coves	.48	sword	2.67
12	cow	2.86	cows	2.43	jeep	2.38
13	crab	2.28	crabs	1.99	sage	1.81
14	creed	1.72	creeds	.95	soap	2.71
15	crime	3.25	crimes	2.63	pan	2.56
16	cub	1.84	cubs	1.78	thumb	2.61
17	dean	2.61	deans	.60	cage	2.75
18	dog	3.48	dogs	3.11	nut	2.74
19	doll	2.81	dolls	2.30	path	2.94
20	dome	1.88	domes	1.00	paw	2.05
21	dove	2.13	doves	1.57	flame	2.51
22	earl	2.35	earls	1.08	plum	2.05
23	fad	1.57	fads	.70	corn	2.61
24	fern	1.46	ferns	1.08	bath	3.00
25	frog	2.43	frogs	1.98	sheet	2.67
26	fur	2.46	furs	1.83	soup	2.88
27	game	3.58	games	3.16	tent	2.65
28	gem	1.96	gems	1.60	bait	2.59
29	globe	2.32	globes	.95	hen	2.03
30	gnome	1.40	gnomes	1.23	queue	1.63
31	gown	2.42	gowns	1.93	dry	3.19
32	grad	2.04	grads	.90	den	2.34
33	grave	2.95	graves	2.29	sell	3.39
34	grub	2.03	grubs	1.20	bran	1.68
35	gym	2.73	gyms	.95	kite	1.89
36	hall	3.20	halls	2.25	wolf	2.58
37	head	3.80	heads	3.19	golf	2.78
38	heir	2.23	heirs	1.58	shell	2.61
39	hill	2.96	hills	2.79	cheek	2.45
40	hole	3.24	holes	2.75	tray	2.45

Table A2 – Stem sub-experiment triplets 41–80 in Experiments 1 & 2.

	Singular	Freq.	Plural	Freq.	Baseline	Freq.
41	hub	1.79	hubs	1.00	fir	1.23
42	hue	1.51	hues	1.00	lore	1.46
43	hymn	1.80	hymns	1.57	gray	2.73
44	isle	1.59	isles	.85	grass	2.74
45	jail	3.23	jails	1.58	grew	3.06
46	jaw	2.45	jaws	2.01	mill	2.28
47	keg	2.00	kegs	1.57	fray	1.54
48	lawn	2.63	lawns	1.70	sill	1.30
49	league	2.78	leagues	1.95	pay	3.69
50	leg	3.20	legs	3.27	pine	2.33
51	lid	2.34	lids	1.43	plan	3.55
52	limb	2.29	limbs	2.03	pry	2.27
53	mane	1.45	manes	.48	ray	2.87
54	meal	3.02	meals	2.54	weed	2.46
55	mode	2.30	modes	1.23	stay	3.83
56	mood	3.11	moods	1.96	lie	3.53
57	mule	2.33	mules	1.81	sly	2.05
58	nerve	2.92	nerves	2.65	way	3.92
59	noun	1.40	nouns	1.08	steam	2.61
60	ore	1.64	ores	1.18	stow	1.76
61	pang	1.51	pangs	1.26	lake	2.90
62	pew	1.60	pews	.90	bush	2.61
63	phone	3.65	phones	2.70	tomb	2.15
64	plain	2.92	plains	1.85	ring	3.32
65	pod	2.11	pods	1.70	chest	3.07
66	pub	2.06	pubs	1.23	ram	2.30
67	rod	2.42	rods	1.80	nose	3.33
68	rogue	2.06	rogues	1.26	tie	3.17
69	screen	2.88	screens	1.91	bell	3.02
70	shawl	1.66	shawls	.70	room	3.80
71	shrine	1.97	shrines	1.04	blue	3.40
72	sleeve	2.38	sleeves	2.12	bang	2.77
73	slug	2.28	slugs	1.90	tang	1.84
74	snail	1.74	snails	1.64	tin	2.43
75	teen	2.12	teens	1.92	dust	2.91
76	theme	2.65	themes	1.65	eye	3.51
77	thorn	1.86	thorns	1.73	rye	2.15
78	tier	1.49	tiers	.95	zoo	2.59
79	tone	2.81	tones	1.94	land	3.32
80	toy	2.75	toys	2.64	ham	2.53

Table A3 – Stem sub-experiment triplets 81–90 in Experiments 1 & 2.

	Singular	Freq.	Plural	Freq.	Baseline	Freq.
81	trend	1.90	trends	1.42	hum	2.16
82	trial	2.98	trials	2.18	clay	2.33
83	tribe	2.29	tribes	1.81	lung	2.38
84	tub	2.66	tubs	1.63	die	3.67
85	wad	1.89	wads	.90	green	3.28
86	wall	3.32	walls	2.95	storm	2.92
87	wing	2.76	wings	2.80	gum	2.65
88	yard	2.89	yards	2.70	bow	2.79
89	yarn	1.79	yarns	.95	farm	2.86
90	zone	2.79	zones	1.82	bed	3.61

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Table A4 – Phonological sub-experiment triplets in Experiment 1.

	Superstring	Freq.	Substring	Freq.	Baseline	Freq.
1	branch	2.57	bran	1.68	sand	2.79
2	cube	1.96	queue	1.63	pole	2.60
3	dent	2.10	den	2.34	scout	2.61
4	drive	3.57	dry	3.19	chin	2.67
5	firm	2.99	fir	1.23	inch	2.70
6	frame	2.72	fray	1.54	pump	2.66
7	grape	2.14	gray	2.73	mug	2.42
8	grasp	2.31	grass	2.74	pin	2.74
9	groom	2.40	grew	3.06	loaf	2.21
10	lice	1.79	lie	3.53	sword	2.67
11	lord	3.30	lore	1.46	trash	2.91
12	milk	3.10	mill	2.28	grain	2.26
13	pail	1.61	pay	3.69	cage	2.75
14	pint	2.09	pine	2.33	corn	2.61
15	plant	2.92	plan	3.55	hike	2.40
16	price	3.22	pry	2.27	soap	2.71
17	rave	1.95	ray	2.87	pan	2.56
18	ride	3.49	rye	2.15	thumb	2.61
19	self	2.73	sell	3.39	jeep	2.38
20	shelf	2.44	shell	2.61	nut	2.74
21	silk	2.54	sill	1.30	path	2.94
22	slice	2.55	sly	2.05	paw	2.05
23	stale	2.12	stay	3.83	flame	2.51
24	stove	2.45	stow	1.76	plum	2.05
25	tank	2.83	tang	1.84	steam	2.61
26	tint	1.20	tin	2.43	bath	3.00
27	trail	2.80	tray	2.45	hen	2.03
28	type	3.28	tie	3.17	soup	2.88
29	whale	2.37	way	3.92	tent	2.65
30	zoom	2.04	zoo	2.59	sheet	2.67
31	ramp	2.01	ram	2.30	ink	2.44
32	bank	3.20	bang	2.77	golf	2.78
33	hump	2.21	hum	2.16	wolf	2.58
34	claim	2.95	clay	2.33	tomb	2.15
35	bone	2.93	bow	2.79	cheek	2.45
36	dime	2.68	die	3.67	lake	2.90

Table A5 – Semantic sub-experiment triplets in Experiment 2.

	Sem A	Freq.	Sem B	Freq.	Baseline	Freq.	Sem. LSA
1	bag	3.40	purse	2.83	dent	2.10	.54
2	beast	2.74	lion	2.52	cube	1.96	.51
3	beef	2.81	steak	2.72	branch	2.57	.52
4	blade	2.59	knife	3.10	drive	3.57	.58
5	bread	2.96	dough	2.61	firm	2.99	.59
6	bridge	3.02	road	3.44	frame	2.72	.3
7	car	3.71	wheel	2.93	grape	2.14	.32
8	chair	3.19	stool	2.20	groom	2.40	.55
9	class	3.39	school	3.66	grasp	2.31	.35
10	cloud	2.59	rain	3.16	milk	3.10	.53
11	crown	2.56	king	3.23	plant	2.92	.48
12	deck	2.80	ship	3.07	pint	2.09	.85
13	dirt	2.91	mud	2.71	price	3.22	.5
14	dish	2.65	bowl	2.83	lice	1.79	.63
15	door	3.72	lock	3.27	pail	1.61	.7
16	duck	2.85	bird	3.08	rave	1.95	.51
17	earth	3.37	moon	3.07	ride	3.49	.4
18	face	3.75	smile	3.25	self	2.73	.76
19	fire	3.60	smoke	3.28	shelf	2.44	.48
20	fort	2.61	war	3.41	silk	2.54	.31
21	girl	3.79	boy	3.79	slice	2.55	.53
22	heart	3.66	blood	3.55	stale	2.12	.65
23	hike	2.40	camp	3.04	stove	2.45	.49
24	hood	2.68	coat	3.10	tank	2.83	.39
25	horn	2.77	noise	3.10	tint	1.20	.45
26	juice	2.92	fruit	2.85	trail	2.80	.37
27	neck	3.29	throat	3.09	lord	3.30	.44
28	pig	3.02	fat	3.31	type	3.28	.31
29	pile	2.72	junk	2.76	whale	2.37	.5
30	prince	2.84	queen	3.08	zoom	2.04	.58
31	sand	2.79	beach	3.11	ramp	2.01	.73
32	shoe	2.95	boot	2.57	hump	2.21	.3
33	spoon	2.43	fork	2.50	bank	3.20	.48
34	star	3.26	sun	3.29	claim	2.95	.35
35	tune	2.74	song	3.29	bone	2.93	.74
36	voice	3.38	sound	3.61	dime	2.68	.44

Table A6 – Non-words in Experiments 1 & 2.

	IPA transcription						
1	stæs	veɪk	nɔl	leɪʤ	ʤup	ɹɛl	faʊʤ
2	dut	vɪŋ	neɪʤ	ɹæs	fɹu	vɪk	slɛnt
3	faɪz	deɪmp	neɪz	væp	gɛd	zɛl	fæsp
4	fɛt	ʤɑɹt	peɪm	vaɪt	kus	plin	fɪsk
5	hɛt	gɹiɹ	plu	wʌŋ	nɑp	blaɪl	ɹɛsp
6	hoʊk	kɑɹk	bɪŋk	ɹist	nik	bɹæm	fænt
7	ɹeɪg	ploʊn	fæmp	pɹɛnt	ɹɪn	ʤænd	voʊ
8	kloʊ	pɹil	bɹil	deɪk	sum	flʊk	kɝʃ
9	naɪd	pɹim	fɹɛl	kit	woʊn	nʊd	plɔɹ
10	naɪz	pɹoʊd	fɹɛs	klaɪ	dist	glɝ	hɔb
11	nʌk	ʃʌst	gɹɪʃ	maɪd	fɹɪʃ	glɛs	ʤeɪɹ
12	ɹɪl	tɑɹk	gɹɪk	næs	nɝθ	gɹaʊd	skɹɑk
13	sʌt	tɹɑk	θɹis	nɪŋ	dæk	Nup	
14	tɪg	ʧɔɹn	skaʊn	vɑk	fæk	wʌm	
15	fɹeɪk	lɔɹs	ɹoʊk	wæf	fin	tɛʤ	
16	bɹɑp	pɛs	nɪm	ziɹ	fun	sɪʤ	
17	kweɪz	klɔs	lʌd	gænd	gid	ɹaɪnθ	
18	pɹæn	stɪp	sʌf	hɛst	glaɪ	blæp	
19	ɹɑɹt	nim	tɝts	kɹɪŋ	heɪd	lʌb	
20	ʃɪns	lɑɹ	tɹʌnθ	plɛl	saɪl	stɔʃ	
21	tɹæθ	kɪnt	tɹʌsk	sɝt	sneɪ	ʤʌm	
22	baɪs	nin	ʌk	skɛs	tɹoʊ	bɹaɪnt	
23	dɪt	næf	gleɪ	tɑɹn	skɹɛd	dɪst	
24	heɪv	maɪɹk	goʊg	stɑt	dʌft	sʌnt	
25	mɑt	neɪnt	flɛg	stiz	dɹiz	feɪʤ	
26	pɛʧ	sæmp	lil	wʌst	dɹit	paɪt	
27	sku	ɹɑʧ	stuk	ʤaɪt	gɹɛl	ɹɔɪs	
28	dɑɹd	slɑk	kʌg	ʤʌŋ	kɛsk	vʌmp	
29	dɹæd	snil	kɔʃ	gʌb	kɛst	skeɪn	
30	paɪs	bɪm	blɔɹn	ɹɔl	kleɪs	spɝl	
31	pɹiz	daɪt	skæl	ʃɪŋ	kleɪt	nɛsk	
32	slɪg	dɑɹ	jʌf	ʧeɪd	plɪn	fɪk	
33	fʌt	ʤɛk	nɪld	vɛs	sɛlk	plæt	
34	gaɪn	ʤɪŋ	gɹɑk	dɑsk	ʧɝt	wɑst	
35	gʊk	fik	sæsk	pɹif	fæʃ	lɑm	
36	lʌn	gæn	klæsk	stif	fɔɪd	veɪ	
37	lɛk	gɪŋ	gɹi	tɹæt	gim	ʌst	
38	pɹu	hɪŋ	blɛn	tɹɔɹ	hæp	slʌʧ	
39	ɹɛt	hɔɪs	ʌft	blaɪ	kɛs	ʤɪk	
40	ɹin	hus	fip	dæg	neɪn	stɹoʊt	

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