FORM PRIMING BY DISCONTINUOUS CONSONANT LETTER STRINGS IN VISUAL MASKED PRIMING

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ABSTRACT

We report on a visual masked priming study that tests whether English verbs are primed by their consonant graphemes in isolation (e.g. whether *grw* primes *GROW*) and whether priming for such prime-target pairs differs for regular versus irregular verbs (e.g. *walk*/*ed* vs. *grow*/*grew*, respectively). We hypothesized that constituent consonant strings would facilitate target recognition based on previous work exploring subset priming [5]. We further hypothesized that the added consistency of consonants over vowels in the morphological paradigms of irregular verbs would increase priming on the basis of related findings in the processing of Semitic languages (though such consonant strings may constitute morphemes in those languages; see [8]). We found that, while all verbs were primed by their constituent consonant strings, the size of the facilitation effect did not differ between regular and irregular verbs.

Keywords: visual word recognition, subset priming, morphology

Acknowledgements: Thanks to members of the Psycholinguistics and Computational Linguistics Lab at the University of Arizona, the audience at the 11th International Conference on the Mental Lexicon, and two anonymous reviewers for useful discussion. Any errors are our own.

1. INTRODUCTION

Past work using the visual masked priming paradigm [6] has found that primes consisting of only subsets of the graphemes in the target word facilitate recognition of that word (e.g. *blcn* primes *BALCON* in French [13]; see also [10]). Duñabeitia and Carreiras [5] extended this work by comparing priming by consonant-only subset primes and vowel-only subset primes in Spanish and found that only the former significantly facilitated the recognition of the target word (e.g. *csn* primed *CASINO*, but *aia* did not prime *ANIMAL*). They conducted several follow-up experiments to establish that the consonant advantage in subset priming was not due to the tendency for consonants to have higher letter frequency (subset primes consisting of low-frequency consonant letters likewise prime, while vowel subset primes do not prime regardless of letter frequency); it was also not due to the tendency for more repetition in the vowel-only primes (subset primes consisting of repeated consonants likewise prime). Finally, they found that the consonant advantage in subset priming is unlikely to be due to phonological processing, as the effect persists at short prime durations that otherwise neutralize phonological processing effects.

To explain the restriction of subset priming to consonant subset primes, Duñabeitia and Carreiras [5] proposed the *Lexical Constraint Hypothesis* with the following chain of reasoning: (1) Attested languages have more consonants than vowels, so (2) languages have fewer possible combinations of vowels than consonants, so (3) more words share vowel substrings than consonant substrings, and so (4) consonant information (e.g. in the form of a consonant-only subset prime) constrains lexical competitors more than does vowel information. The increased restriction placed on lexical competition by consonants results in a facilitation effect being elicited by consonant-only subset primes but not vowel-only ones.

However, results from Semitic languages indicate that additional factors may constrain the subset priming effect. Specifically, in Semitic languages (e.g. Maltese, Hebrew), consonantal letter strings have likewise been found to facilitate word recognition, but only when such strings correspond to root morphemes [8,9]. Native Semitic word stems consist of two discontinuous morphemes: a (tri)consonantal root (e.g. *ktb* 'writing') and a word pattern which can contain vowels and a limited set of consonants. The intercalation of root morphemes and word patterns results in groups of morphologically-related words (e.g. ***k****i****t****e****b*** 'to write', ***k****i****tt****ie****b*** 'writer', ***k****i****tb****a* 'writing', ***kt****ie****b*** 'book', etc.), and subset primes comprising the letters of a root morpheme facilitate recognition of related words. Maltese is unique among the Semitic languages in that it possesses a lexicon composed of roughly half Semitic-origin words which consist of roots and word patterns and half words borrowed from Sicilian, Italian, and English which do not [2,4]. Using visual masked priming, Geary and Ussishkin [9] found that exposure to triconsonantal letter strings facilitates the recognition of native Maltese words, for which such strings comprise the word's root morpheme (e.g. *frx* primes the native word *FIREX* 'to spread'), but not non-native words for which such strings are non-morphemic (e.g. *pnġ* fails to prime the non-native word *PINĠA* 'to paint').

This result suggests that the role of consonant letter substrings in word processing may depend on language-specific morphological patterns in addition to the combinatorial properties of consonants and vowels in the lexicon. In this paper, we test whether consonant letter substrings elicit a larger subset priming effect for irregular verbs like *grow*/*grew* than for regular verbs like *walk*/*walked* in English: Consonants are the only source of stability across inflectional forms for irregular verbs, making them more closely tied to word identity for irregular verbs than for regular verbs, and so we may expect to find a greater priming effect by consonant letter strings for irregular verbs than for regular ones. Finding greater consonant subset priming for irregular verbs in English would be analogous to finding subset priming for native Maltese words but not non-native Maltese words (except that in the Maltese case such strings comprise part of the derivational morphology) and would support the hypothesis that language-specific morphological patterns, in addition to combinatorial properties of letters, influence subset priming.

2. METHOD

2.1. Materials

We conducted a visual lexical decision task using the masked priming paradigm of Forster and Davis [6]. Visual targets comprised 60 English verbs (30 regular, 30 irregular) and 60 non-words. All targets were 3-6 letters long with 2-4 consonant graphemes. Regular and irregular real-word targets were matched for frequency using the SUBTLEX-US $\log_{10}$ contextual diversity values [3]: $M_{\text{Reg}} = 2.99$, $M_{\text{Irr}} = 3.09$. For each real-word target, a non-word counterpart was built by changing some of the real word's consonant graphemes (e.g. the graphemes *rn* of *burn* were changed to *lf*, producing the matched non-word *bulf*). Real and non-words were matched for orthographic neighborhood density.

Real-word targets occurred in 3 priming conditions, which are illustrated in Table 1: an **Identity** condition; a **Related** condition, in which the primes were subset primes containing the consonant graphemes of the target; and an **Unrelated** condition. Unrelated primes consisted of a consonantal letter string matched with the related primes in number of consonant graphemes but containing no overlapping letters.

Table 1: Example prime-target pairs in the three priming conditions for regular and irregular targets.

Condition	Regular		Irregular	
Identity	*burn*	*BURN*	*grow*	*GROW*
Related	*brn*	*BURN*	*grw*	*GROW*
Unrelated	*tly*	*BURN*	*ctd*	*GROW*

Each non-word target was paired with a single related prime (e.g. *blf* primed *BULF*, *clw* primed *CLOW*). Three lists counter-balanced for priming condition for the real-word targets were constructed using a Latin square design. Each participant was assigned randomly to one list, and so judged the lexicality of each real-word target in one and only one of the three priming conditions.

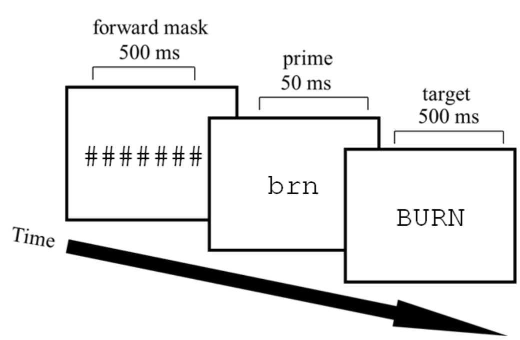
2.2. Participants

Forty-eight native monolingual English speakers with normal or corrected-to-normal vision (mean age = 21.5 years; 12 identified as male, 36 identified as female; 8 identified as left-handed, 40 identified as right-handed) participated in the experiment for extra credit. All participants were recruited from the University of Arizona Linguistics Department subject pool.

2.3. Procedure

Participants were seated in a sound-attenuated booth in front of a Windows desktop computer. The experiment was conducted in DMDX [7] using the visual masked priming paradigm [6]. Figure 1 illustrates the structure of a trial.

Figure 1: The structure of a trial.



First, a forward mask consisting of a row of hashtags was displayed for 500 milliseconds (ms). Then, the forward mask was replaced by the prime, which appeared in lowercase letters and which was displayed for 50 ms. Then, the prime was replaced by the target, which appeared in uppercase letters. Participants viewed the target for 500 ms, and had 3000 ms from target onset to judge the lexicality of the target and respond. Participants responded by pressing a bumper button on a Logitech Gamepad F310 labelled "YES" for a real-word and a bumper button labelled "NO" for a non-word. Accuracy and reaction time (RT) were recorded.

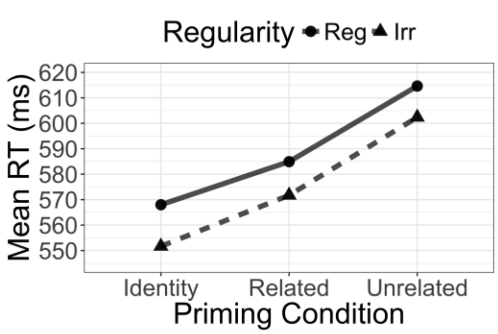
3. PREDICTIONS

Following previous studies that have used the subset priming paradigm [5, 10, 13], we expect faster RTs in both the Identity and Related conditions relative to the Unrelated condition. If the subset priming effect is influenced by patterns of consonant stability across morphologically related forms, as was found in Maltese [9], we anticipate a larger effect in the related condition for irregular verbs than for regular verbs.

4. RESULTS

Figure 2 shows mean RT in milliseconds (ms) to irregular and regular real-word verb targets on accurate trials in the Identity, Related, and Unrelated priming conditions.

Figure 2: Mean RT in the three priming conditions for regular (Reg) and irregular (Irr) verb targets.



Negative reciprocal RTs to real-word targets on trials in which a participant provided the correct response were analyzed using a REML-fitted linear mixed effects regression (lmer) analysis in R [14] using the lme4 package [1]. Fixed effects included Priming Condition (levels: Identity, Related, Unrelated; reference level: Unrelated), Regularity (levels: Regular, Irregular; reference level: Regular), the Priming Condition by Regularity interaction, word frequency (operationalized as the $\log_{10}$ contextual diversity measure from the SUBTLEX-US corpus, [3]), and neighborhood density (measured as the number of neighbors at edit distance 1 [11]). The interaction of Priming Condition by Regularity was included to test the hypothesis that priming in the related condition would be greater for irregular than for regular verbs.

Subjects and Items were included in the model as random effects. Likelihood ratio tests comparing the ML-fitted random intercepts model with ML-fitted models having more complex random effects structures suggested that random slopes for Priming Condition by-subject, Priming Condition by-item, and Regularity by-subject were not justified for this dataset, and so random slopes were not included in the final model. Outliers were removed using a model-based trimming procedure that takes a linear model and removes from the fitted dataset data points for which the residual standard score is more than 2.5 units from the mean of zero (K.I. Forster, personal communication, March 9, 2016). Satterthwaite approximations for degrees of freedom were simulated using the lmerTest package [12] in order to compute *p*-values and assess significance. Table 2 provides a summary of the model output.

Priming in the Identity and Related conditions was significant ($t(3500) = -7.4$, $p < 0.001$ and $t(3500) = -4.0$, $p < 0.001$, respectively). As predicted, participants responded faster to real-word targets in the identity and related conditions than in the control condition. Regularity and the Priming Condition by Regularity interaction at both the Identity and Related levels of Priming Condition were not significant ($p > 0.05$ for all three), indicating that, contrary to our prediction, consonant subset primes did not elicit greater priming for irregular verbs than for regular verbs.

5. DISCUSSION

Using visual masked priming with lexical decision, we obtained facilitation for English verbs when primed by subset primes containing only the constituent consonant letters of the target (e.g. *brn* priming *BURN*), replicating the subset priming effects found in previous work [5, 10, 13]. We further hypothesized on the basis of related findings in Semitic languages that consonant consistency across morphological paradigms might increase the priming effect caused by consonant subset primes. That is, we might find a larger subset priming effect for irregular verbs like *grow/grew* than for regular verbs like *walk/walked*, for the latter of which consonant letters seem more closely tied to word identity due to their stability across inflected forms relative to vowels letters. However, we found no evidence to support this hypothesis. This contrasts with results from Maltese, where subset priming is found only when the letters comprise a root morpheme [9]. One possibility is that consonant stability across derivationally-related forms, as in the Semitic case, influences lexical representation and storage differently than consonant stability across inflectionally-related forms, as in the English irregular verb case tested here.

Table 2: Output of the statistical model (Irr = Irregular).

Condition	Estimate	Std. Error	*df*	t	Pr(>|t|)	
(Intercept)	-1.28e-03	7.35e-05	99	-17.4	< 0.001	***
PrimeIdentity	-1.34e-04	1.81e-05	3500	-7.4	< 0.001	***
PrimeRelated	-7.23e-05	1.81e-05	3500	-4.0	< 0.001	***
RegularityIrr	-1.33e-05	2.68e-05	113	-0.5	> 0.050	
Frequency	-1.72e-04	1.95e-05	58	-8.8	< 0.001	***
Neighbors	5.43e-06	2.01e-06	57	2.7	> 0.009	**
PrimeIdentity:RegularityIrr	-2.90e-05	2.52e-05	3500	-1.2	> 0.050	
PrimeRelated:RegularityIrr	-1.87e-05	2.52e-05	3500	-0.7	> 0.050	

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