To appear in *Language, Cognition and Neuroscience*
Vol. 00, No. 00, 00 Month 2015, 1–26

Auditory masked priming in Maltese spoken word recognition

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(*Received 5 July 2013; accepted 4 December 2014*)

This study investigated lexical access in Maltese, an understudied Semitic language. We report here on a series of four lexical decision experiments designed to test the hypothesis that the consonantal root and the word pattern may each prime lexical access in Maltese. Priming of morphologically related forms is generally taken as evidence consistent with morphological decomposition in processing. Here, we used two speech priming techniques: auditory priming in which primes and targets were equally audible, and auditory masked priming in which primes are masked from conscious perception by volume-attenuation and compression. Our results show priming of targets by forms sharing a consonantal root, but not by forms sharing a word pattern.

Keywords: Auditory priming; lexical access; Maltese; Semitic; subliminal speech priming; root and pattern morphology

Introduction

A central issue in spoken word recognition concerns the role of morphological decomposition. Most studies addressing this issue involve languages with typologically common linear morphology, such as English, in which most words are formed by concatenatively stringing together contiguous elements such as prefixes, stems, and suffixes. Several competing model types have been proposed to account for morphological processing in spoken word recognition, and these models differ crucially with respect to the role allocated to the sub-elements or morphemes that compose words. For models in which morphologically complex words are holistically stored in the lexicon, automatic decomposition into morphemes is not a component of lexical access (e.g., Tyler et al., 1988). In contrast, other models include such a component, whereby complex forms are recognized on the basis of their constituent morphemes (e.g., Meunier and Segui, 1999; Taft et al., 1986; Wurm, 2000). A third type of model allows for both decompositional and holistic retrieval pathways, in which the preferred route of lexical retrieval for any given word may be influenced by factors such as familiarity, frequency, semantic transparency, and/or conditional probability (e.g., Balling and Baayen, 2008; Marslen-Wilson et al., 1994; Schriefers et al., 1991; Wurm, 1997). Semitic languages provide a unique test-case for these models because of their unusual, non-concatenative morphology: Semitic words are typically composed of a discontiguous consonantal root combined with a word pattern (or *binyan*) that specifies vowels and the ordering among consonants and vowels (see the section on Maltese below for more detail).

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Previous cross-linguistic work

Earlier work on auditory processing in Semitic languages is sparse, though there is a well-established line of research in the visual modality on priming effects on processing in Hebrew and Arabic. An advantage of using the visual modality in priming investigations is that primes can be presented for a sufficiently short period that they are not consciously perceived by participants. As summarized and reviewed by Forster et al. (2003), masked priming presents numerous advantages in the study of lexical access because it taps extremely early processes in word perception. In a series of papers reporting on experiments using masked visual priming, Frost et al. (1997), Deutsch et al. (1998), and Frost et al. (2000) demonstrate that primes sharing a root with a target facilitate lexical access in Hebrew nouns and verbs. On the basis of these results, these authors argue that models of Hebrew visual word recognition must reference the consonantal root. The results reported by Boudelaa and Marslen-Wilson in a series of studies of Arabic (Boudelaa and Marslen-Wilson, 2011, 2001b, 2004a,b, 2005; Boudelaa et al., 2010) are similar, with strong support for the role of the root in lexical access. Priming by word patterns, as opposed to by consonantal roots, has been found in both Hebrew and Arabic, but appears to be less robust. In Hebrew, Deutsch et al. (1998) find word pattern priming in verbs, but not in nouns, and word pattern priming in Arabic has been reported to be less reliable than root priming (Boudelaa and Marslen-Wilson, 2011, 2005; Boudelaa et al., 2010).

However, these earlier studies on visual word recognition in Hebrew and Arabic unavoidably encounter a potentially significant confound, since both languages are written with an orthography that heavily favors consonants over vowels. Because of this, the orthographic representations of many words are equivalent to orthographic representations of their consonantal roots; hence, the possibility cannot be ruled out that evidence for visual consonantal root-based processing in Hebrew and Arabic is due to the strong orthographic bias inherent in visually presented primes. Further, given evidence (Morais et al., 1986) that orthographic knowledge influences lexical structure, the orthographies of Hebrew and Arabic represent a confound that cannot be entirely mitigated by carrying out experiments on Hebrew and Arabic in the auditory modality. As noted by Perea et al. (2012), Maltese does not present this confound because it is written in the Latin alphabet, and consistently represents both vowels and consonants. As a consequence, the written form of a word in Maltese does not as directly implicate its division into root and word pattern morphemes.

Maltese

The goal of this paper is to investigate the role of the consonantal root and the verbal pattern in lexical access in the Semitic language Maltese. Maltese is most closely related to varieties of Arabic spoken in North Africa. It is spoken in the Republic of Malta, where it has official status and is also recognized as the national language; English also has official status in Malta due to extensive British contact and influence for two hundred years. As a result, a large proportion of the Maltese population is bilingual as native speakers of both Maltese and English. Semitic languages in general are a valuable object of study with respect to the architecture of the mental lexicon due to their unusual word structure. In Semitic, words tend to be composed not of a string of contiguous elements, but rather of a root embedded within a word pattern (McCarthy, 1981, among many others). Roots are composed of consonants (typically three consonants, but occasionally two or four consonants), while word patterns are signaled by the segmental and prosodic scaffold in which the root appears: the sequence of vowels, and presence of prefixes and consonant gemination. Roots contribute content-based meaning, while word patterns contribute grammatical meaning. Because neither the root nor the word pattern is ever pronounced in isolation, the building blocks of words in Semitic are more abstract than in most languages more commonly investigated to study lexical access, such as English, that primarily employ contiguous elements. For instance, Table 1 illustrates Maltese words formed from the root /ktb/ as it appears in a variety of word patterns. "C" here stands for "consonant" and "V" for "vowel"; the subscript numerals following each consonant indicate each of the three root consonants.

Table 1: about here

Within the larger class of word patterns, *binyanim* (singular = *binyan*, from the Hebrew word meaning "building, structure"; other terms for *binyan* found in the literature include *measure*, *form*, and *theme*.) are a type of word pattern specific to verbs, and each binyan forms a category that phonologically combines consonantal roots with a fixed prosodic structure (Ussishkin, 2005). Maltese has eleven verbal binyanim. They are illustrated in Table 2, which provides the number used by traditional Maltese grammatical descriptions for each binyan, an example of a verb in each Maltese binyan along with its word pattern prosody, and the morpho-syntactic function associated with each binyan. All examples are given in the uninflected third person masculine singular perfective verb form, which in Maltese corresponds to either an infinitival citation form (e.g., "to break") or to a past tense form with the pronoun *he* (e.g., "he broke").

Table 2: about here

The binyan system forms a part of the derivational component of the language, and much of it is quite productive morphologically; for Semitic verbs in Maltese, forms such as passives and reflexives may only be derived within this system. As in other Semitic languages, no root is instantiated in every binyan.

The morphological structure of Maltese resembles that of other Semitic languages with respect to the Semitic portion of its vocabulary. Maltese has had extensive contact with Indo-European languages (most notably Sicilian and Italian, followed by English) since the Norman conquest of the eleventh century, resulting in a split vocabulary in which roughly half of lexical items are Indo-European in origin and primarily display linear (i.e., prefixing and suffixing) morphology. The remaining vocabulary is of Semitic origin and displays typical root-and-pattern morphology (Bovingdon and Dalli, 2006; Mifsud, 1995). As in other Semitic languages, Maltese verbs of Semitic origin are defined by a limited set of binyanim, each of which tends to be associated with a given morpho-syntactic role (e.g., valency, tense, voice, etc.).

Why Maltese?

Maltese has a number of properties that make it uniquely well-suited to contribute to our understanding of lexical access in Semitic, and thereby in language more broadly. A major factor is its Roman alphabet-based orthographic system, which differs from the orthographies of other Semitic languages in representing consonants and vowels equally. Previous work investigating lexical access in Semitic languages has focused mainly on visual word processing in Hebrew and Arabic, in which the consonant-based orthographies closely reflect morphological structure. The Maltese writing system encodes both consonants and vowels in a consistent manner, and thus the literate Maltese speaking participant population is not trained by orthography in the same way to attend to any relationship between the consonant-vowel distinction and the morphological structure of Semitic words in the language. A further point is that experiments are easier to design and run in Maltese than in many other Semitic languages, due to both the nature of the writing system and the relative ease of access to native speaker participants and appropriate testing facilities. Finally, as noted above Maltese is unusual in that it has a split Indo-European/Semitic lexicon that exhibits corresponding concatenative and nonconcatenative word formation processes. Both systems are active parts of the Maltese grammatical system: in a nonce-word elicitation task, Twist (2006) showed that both morphological systems are productively used by native Maltese speakers. As a consequence, Maltese may provide an opportunity to compare lexical access in these different morphological systems within one subject population; see the General Discussion below.

Why the auditory modality?

Previous work in Maltese lexical access (Twist, 2006) has been limited to visual masked priming. In line with results in the visual modality reported by Frost et al. (1997) and Boudelaa and Marslen-Wilson (2001a), Twist (2006) reports facilitated lexical access for Maltese prime-target verb pairs sharing a root, but not a binyan. Here, as a way to further distance participant behavior from orthographic influence, we chose to investigate lexical access in the auditory, rather than visual modality. However, until recently, no technique has been available to mask auditory primes in a way that is functionally similar to the masked visual priming technique. Kouider and Dupoux (2005) recently innovated a method for masking auditory primes by durationally compressing them and embedding them in reversed compressed speech. In work on French (Kouider and Dupoux, 2005) and English (Davis et al., 2010), auditory primes that are masked in this way have been shown to reveal faciliated lexical access for the identity condition in a lexical decision task. These earlier studies on French and English have also tested various types of form priming, in which primes and targets are morphologically, semantically, or phonologically related but non-identical. No form priming effects, though, have been found in work on French or English using this technique. In the current studies on Maltese, we carried out two sets of priming experiments. In one set we used standard, non-masked auditory primes (supraliminal priming). In the second set, we used masked auditory primes (subliminal priming). Use of these techniques allows us to address the overlapping problems inherent in earlier work using the visual modality. In addition, by virtue of masking the primes, the use of masked auditory priming enables any priming effects found to be more clearly ascribed to online, subconscious processing. Visually masked primes are thought to be processed online, without advantages conferred by episodic memory (Forster et al., 2003), and so it is likely that auditory primes, when masked from conscious awareness, may also be processed online. We provide evidence below that primes in the masked condition are not consciously processed.

Experiment 1a

Experiment 1a involved supraliminal priming in which all subjects heard, on each trial, an audible prime followed by a target and were asked to perform a lexical decision on the target. In this experiment, prime-target pairs in the related priming condition shared a consonantal root (e.g., prime = *siket* 'to be quiet', target = *sikket* 'to silence'). This experiment was designed to test whether prime-target pairs sharing a root would yield a facilitatory priming effect.

Methods

Participants

68 subjects participated in Experiment 1a (22 male subjects, 46 female subjects). All subjects in this as well as in all subsequent experiments reported normal vision and hearing. The mean age of subjects in Experiment 1a was 23.75 years, and the median age was 20 years. Subjects in Experiment 1a and all subsequent experiments typically were undergraduate students at the University of Malta, and were recruited in classes as well as by email and the campus news service at the University of Malta. No subject participated in more than one experiment of the four experiments reported here. All subjects were bilingual speakers of Maltese and English, which is typical in Malta where both languages have official status.

Materials

Each subject was presented with 36 pairs of real-word primes paired with real-word targets, with 12 targets in each of three priming conditions: unrelated or control; identity; and morphologically related. In Experiments 1a and 2a, the morphologically related prime-target pairs shared a consonantal root, while in Experiments 1b and 2b, the morphologically related prime-target pairs shared a verbal binyan (i.e., a word pattern). No consonantal root occurred more than once in any list, except in the case of morphologically related prime-target pairs in Experiments 1a and 2a. For each experiment, we constructed three lists counterbalanced by priming condition using a Latin square. Each subject was randomly assigned to one of the three lists and heard each of the target items in one of the three priming conditions. Each subject was also presented with 36 items consisting of a nonword prime paired with a nonword target, which were also counterbalanced by priming condition in the same fashion as the items consisting of real word primes paired with real word targets. This design allowed us to test for priming effects in nonword prime-nonword target pairs in the three priming conditions. This was done based on the hypothesis that such items in the identity and related priming conditions might show facilitated lexical decision, which would manifest as a faster RT for the "no" response on such trials. In addition to these 72 lexically congruent prime-target pairs (in which the lexicality of a prime always matched the lexicality of its target), we included as filler items an equivalent number of nonword primes paired with real word targets, as well as real word primes paired with nonword targets. Doing so prevented participants from developing a strategy of guessing target lexicality based on the lexicality of the prime. The total number of such lexically incongruent prime-target pairs was also 72 for each list. Prime-target pairing between the verbal binyanim was balanced, such that each possible pairing was equally represented within each set of lexically congruent (real word prime-real word target; nonword prime-nonword target) and incongruent (real word prime-nonword target; nonword prime-real word target) items.

All real word items were first chosen by manually collecting all 1536 Semitic-origin verbs in Aquilina (2000), the Maltese-English-Maltese dictionary considered to be the authoritative standard dictionary of the Maltese language. All real words used as either primes or targets in this and all subsequent experiments reported here were rated with a mean subjective familiarity of at least 50% on a percentage scale ranging from 0-100% in Francom et al. (2010). The resulting subset of Semitic-origin verbs then underwent a vetting process by a native Maltese-speaking consultant, who removed all words judged likely to be considered archaic, offensive, or otherwise inappropriate for use in the experiments by other native speakers of Maltese.

Next, to create all nonword items, we generated a list of every attested triconsonantal Semitic root of Maltese based on the list of verbs from Aquilina (2000). We then generated the complement set of every possible but unattested triconsonantal root, and eliminated those that would violate well-known phonotactic and morpheme structure constraints of Maltese. For instance, no nonce roots containing two identical initial consonants were used in creating nonwords, following numerous studies on the Obligatory Contour Principle in Semitic and elsewhere (OCP; Greenberg, 1950; Leben, 1973; McCarthy, 1979, 1986, among many others). The resulting set of phonologically legal but unattested roots was then used to create nonword items for both primes and targets in the experiments. Each nonword was created by embedding a nonce root into existing word patterns attested in the four binyanim used in the four experiments (Binyanim 1, 2, 5, and 7). Earlier research (Francom et al., 2010) has shown that these four binyanim are the most densely populated binyanim of Maltese, and in fact were the only four binyanim that yielded sufficient real word items to have sufficient statistical power in our experiments. In order to avoid accidental effects of phonological form priming, in the unrelated priming condition for all lexically congruent prime-target pairs, no prime-target pair involved the same consonant occurring in the same root position. Finally, all non-word items were vetted by a native Maltese speaker who removed any items judged to be inappropriate, for example if they were similar to offensive words, or to existing words in non-standard Maltese dialects.

All items, once selected, were subsequently recorded by a male native speaker of Maltese. The speaker pronounced each item in Standard Maltese; despite the small size of Malta and the relatively small population of Maltese speakers (roughly 400,000), there are numerous dimensions of dialectal variation in Malta, reflecting geographic differences, rural vs. urban differences, and other differences. All items were recorded in a sound-attenuated Whisper Room booth at a sampling rate of 44110 Hz. The native speaker was instructed to read each item from a laser-printed list in Maltese orthography, in a relaxed yet careful manner. Recordings were made while the speaker wore an omnidirectional head-mounted Isomax microphone made by Countryman Associates, which was connected via a Symetrix Audio 302 preamplifier to an Alesis Masterlink 9600. The native speaker pronounced each item three times, and the best token of the three was selected for use in our experiments by a trained research assistant. "Best token" was generally defined as the token with the clearest enunciation, the most neutral intonation, and no non-linguistic intrusions (e.g., coughs, etc.) This token was demarcated and labelled in Praat (Boersma and Weenink, 2011) using a text grid, and extracted and stored as its own .wav file using a Praat script.

Mean duration across all items was 670 ms; for real words, mean duration was 675 ms and for nonwords, mean duration was 666 ms. These .wav files, each corresponding to an individual word or nonword, served as input files for use by a subsequent Praat script which combined these input files into prime-target pairs with an inter-stimulus interval of 150 ms. for Experiments 1a and 1b.

The lists of prime-target pairs for each experiment can be found in Appendix 1. Table 3 shows sample prime-target pairs in each condition for Experiment 1a. Each experiment took approximately 20 minutes for each subject to complete.

Table 3: about here

Procedures

All experiments were conducted at the University of Malta Institute of Linguistics, using desktop computers and E-Prime v. 1.2 software (Psychology Software Tools, Pittsburgh, PA) to present stimuli and record responses. Responses were recorded via a serial response box which measured lexical decision response time (RT) as well as lexical decision accuracy. We measured RT from both target onset and target offset; the results reported below rely on the target onset measurements, though the statistical analyses based on target offset measurements yield an identical pattern of results. During the experiment, subjects were seated in front of a computer screen and wore a pair of ATH-M40f Studiophones by Audio-Technica to hear stimuli. After each trial, subjects performed a lexical decision on the target in each prime-target stimulus pair by pressing a button marked IVA (Maltese for "yes") or LE (Maltese for "no") on the serial response box. Subjects were instructed to respond as quickly and as accurately as possible to each target, with a time-out of 1500 ms; subjects who failed to respond within 1500 ms of trial offset received a visual time-out message (*"no response detected"*) and were then presented with the subsequent trial. Subjects were given feedback after each response via a message printed in Maltese on the computer screen. This message informed them of the accuracy of their response, in addition to providing them with their average percent correct score over the course of the experiment. In this and all subsequent experiments, subjects began with a practice block of twelve randomized prime-target pairs, with three sets of four prime-target pairs in each of the three priming conditions.

Data Preparation and Analyses

Reaction Times (RTs) were measured from target onset, though the results reported below based on this measure were not different when target offset was used instead. Initial analyses revealed pronounced positive skew in the distribution of reaction times, and so reaction times were transformed to the log scale prior to analysis.

Trials on which the log reaction time was greater than 2.5 standard deviations from either the subject or target item mean were excluded in all analyses. In addition, incorrect responses were excluded from the reaction time analyses. The proportion of trials excluded for each reason is shown in Table 4.

In this and all subsequent experiments, reaction times and error rates were analyzed using by-subject and by-target analyses of variance. For the by-subject analyses, priming condition (identity, related, unrelated) was a within-subject factor. For the by-items analyses, priming condition was a within-target factor.

In order to detect reaction time effects more complex than a simple shift of the distribution, an additional analysis was conducted in which reaction time distributions for each subject and priming condition combination were summarized by their 5th, 25th, 50th, 75th and 95th percentiles. This produced an additional within-subjects factor: percentile (five levels). This procedure is a slight modification of the Vincentile analysis of Balota et al. (2008), which involves binning the data using the deciles as break points and computing a mean within each bin. The decision to modify this procedure by using a set of percentiles rather than bin means was made here due to the comparatively small number of observations (12) in each cell. After incorrect responses are excluded, there were fewer than 10 observations left in some cells. Note that in this analysis only, raw reaction times were not log-transformed, since the goal was to detect differences in distribution shape.

Reaction time data was also analyzed using linear mixed effects models with subjects and targets as crossed random effects, but the results were qualitatively similar to those obtained with analysis of variance, and so they are reported in Appendix 2.

Results

Table 4: about here

Figure 1: about here

Real Word Trials

Mean reaction times, error rates, and outlier rates are given in Table 4[1]. Means and modeled standard errors are plotted in Fig. 1 as well. The related-root and identity conditions yielded shorter response latencies compared to the unrelated condition, with a stronger priming effect in the identity condition.

Mean Reaction Time. The overall effect of priming condition was significant ($F_1(2, 134) = 76.28$, $MSE = 0.00626$ sq. log ms, $p < 0.001$; $F_2(2, 70) = 85.07$, $MSE = 0.00306$ sq. log ms, $p < 0.001$; $\min F'(190) = 40.22$, $p < 0.001$), with priming occurring in both the identity condition ($t_1(67) = 10.90$, $p < 0.001$; $t_2(35) = 12.41$, $p < 0.001$) and the related-root condition ($t_1(67) = 10.39$, $p < 0.001$; $t_2(35) = 8.56$, $p < 0.001$). The degree of priming was significantly greater in the identity condition than in the related-root condition ($t_1(67) = 2.30$, $p < 0.05$; $t_2(35) = 2.81$, $p < 0.01$).

Reaction Time Distributions. The Percentile analysis revealed no significant interaction between percentile and priming condition ($F(8, 938) = 0.77$, $MSE = 16802.56$ sq. ms, $p = 0.63$), suggesting that priming effects were realized as simple shifts of the reaction time distribution. The main effect of priming condition revealed the same pattern of significance as in the simple analysis.

Error Rate. The overall effect of priming condition was significant in the by-subjects analysis, but not the by-items analysis ($F_1(2, 134) = 3.45$, $MSE = 0.006$ sq. log ms, $p < 0.05$; $F_2(2, 70) = 2.10$, $MSE = 0.00552$ sq. log ms, $p = 0.13$; $\min F'(152) = 1.31$, $p = 0.26$). The effect appears to be driven by a lower error rate in the related-root condition than in the unrelated condition ($t_1(67) = 2.51$, $p < 0.05$; $t_2(35) = 2.20$, $p < 0.05$). The identity condition did not significantly differ from the unrelated condition ($t_1(67) = 0.70$, $p = 0.48$; $t_2(35) = 0.49$, $p = 0.63$), and the difference between the identity and related-root conditions was marginal ($t_1(67) = 1.93$, $p < 0.1$; $t_2(35) = 1.68$, $p = 0.10$). It appears that there is a somewhat decreased tendency for participants to incorrectly label words as nonwords in the related root condition. This effect goes in the opposite direction of a speed-accuracy tradeoff, with increased accuracy and increased speed in the related-root condition.

Nonword Trials

Mean reaction times, error rates, and outlier rates are given in Table 4. Means and modeled standard errors are plotted in Fig. 1 as well. The identity condition yielded shorter response latencies compared to the related-root and unrelated conditions, but these did not differ from each other. This is consistent with similar nonword repetition priming effects reported in Mimura et al. (1997), where a quicker response for nonwords compared to real words was found in an auditory lexical decision task

[1]Some trials would be excluded according to more than one criterion. As a result, the total amount of missing data is not the sum of the percent missing for each reason.

in a repetition priming condition.

Mean Reaction Time. The overall effect of priming condition was significant ($F_1(2,134) = 113.91$, $MSE = 0.00559$ sq. log ms, $p < 0.001$; $F_2(2,70) = 102.76$, $MSE = 0.00366$ sq. log ms, $p < 0.001$; $\min F'(178) = 54.02$, $p < 0.001$), with priming occurring in the identity condition ($t_1(67) = 12.25$, $p < 0.001$; $t_2(35) = 12.45$, $p < 0.001$) but not the related-root condition ($t_1(67) = 0.51$, $p = 0.61$; $t_2(35) = 0.86$, $p = 0.39$). Latencies in the identity condition were significantly shorter than in the related-root condition ($t_1(67) = 11.92$, $p < 0.001$; $t_2(35) = 11.84$, $p < 0.001$).

Reaction Time Distributions. The Percentile analysis revealed no significant interaction between percentile and priming condition ($F(8,938) = 0.89$, $MSE = 14500.14$ sq. ms, $p = 0.53$), suggesting that priming effects were realized as simple shifts of the reaction time distribution. The main effect of priming condition revealed the same pattern of significance as in the simple analysis.

Error Rate. The overall effect of priming condition was significant ($F_1(2,134) = 18.66$, $MSE = 0.00848$ sq. log ms, $p < 0.001$; $F_2(2,70) = 10.41$, $MSE = 0.00808$ sq. log ms, $p < 0.001$; $\min F'(146) = 6.68$, $p < 0.05$), with more errors in the related-root condition than both the unrelated condition ($t_1(67) = 4.62$, $p < 0.001$; $t_2(35) = 3.49$, $p < 0.005$) and the identity condition ($t_1(67) = 5.26$, $p < 0.001$; $t_2(35) = 3.86$, $p < 0.001$), but no significant difference between the identity and unrelated conditions ($t_1(67) = 1.11$, $p = 0.27$; $t_2(35) = 0.84$, $p = 0.41$). Taken together with the real word trials, this suggests a general tendency for participants to treat targets as real words when the prime shares a root: for word targets this lowers the error rate; for nonword targets it increases it.

Discussion

The results of Experiment 1a point to facilitated lexical retrieval when primes and targets share a consonantal root. This result is consistent with results on Maltese masked visual priming reported in earlier work (Twist, 2006), in addition to earlier work on Hebrew (Deutsch et al., 1998; Frost et al., 2000, 1997; Velan et al., 2005) and Arabic (Boudelaa and Marslen-Wilson, 2001b), all of which reveals consistent facilitatory effects of root priming for verbs in those languages as well. The competition between morphological and semantic factors as central to the effects discussed for these earlier results has consistently been shown to favor morphology (Frost et al., 1997), and further work (Frost et al., 2005) shows that morphology even outweighs orthographic factors in processing, though clearly any orthographic effects here have been controlled to the extent possible given the nature of the Maltese orthographic system, and our use of the auditory modality. Experiment 1a is consistent with all of these findings, but represents the first case of consonant-facilitated priming in spoken word recognition in Maltese. Because our control primes were unrelated words, this experiment cannot directly distinguish between morphological and phonological relationships as the source of the priming effect. However, post-hoc analyses (see Appendix 2) distinguishing primes on the basis of differing degrees of phonological overlap with targets found no effect for degree of phonological relatedness, suggesting that morphological priming contributes to this effect (see General Discussion).

Experiment 1b

Experiment 1b differed from Experiment 1a in that in the related priming condition for Experiment 1b, prime-target pairs shared a verbal binyan, not a consonantal root (e.g., prime = *kiber* 'to grow', target = *siket* 'to be quiet').

As in Experiment 1a, we selected prime-target pairs from Binyanim 1, 2, 5, and 7. Aside from the difference in the related priming condition (in Experiment 1b, prime-target pairs in the related priming condition shared a binyan, not a root), all other details remain identical to those of Experiment 1a. Our motivation here is to determine whether binyan-related prime-target pairs in Maltese exhibit facilitated lexical access the way root-related pairs were shown to do in Experiment 1a.

Methods

Participants

Data was collected from 66 subjects (28 male subjects, 42 female subjects). The mean age of subjects in Experiment 1b was 22.4 years, and the median age was 20 years.

Materials

In Experiment 1b, materials were selected and created identically to those used in Experiment 1a. The difference between Experiment 1a and 1b was that in the related condition, Experiment 1b involved prime-target pairs in the same verbal binyan, whereas in Experiment 1a items in this condition shared a consonantal root. As in Experiment 1a, items in Experiment 1b were evenly balanced across all possible binyan pairings in the four binyanim used. Table 5 shows sample prime-target pairs in each condition for Experiment 1b.

Table 5: about here

Procedures

All procedures in Experiment 1b were identical to those in Experiment 1a.

Results

Table 6: about here

Real Word Trials

Mean reaction times, error rates, and outlier rates are given in Table 6. Means and modeled standard errors are plotted in Fig. 1 as well. The identity condition yielded shorter response latencies compared to the related-binyan and unrelated conditions, but these did not differ from each other.

Mean Reaction Time. The overall effect of priming condition was significant ($F_1(2, 130) = 173.82$, $MSE = 0.00362$ sq. log ms, $p < 0.001$; $F_2(2, 70) = 78.26$, $MSE = 0.00461$ sq. log ms, $p < 0.001$; $\min F'(133) = 53.96$, $p < 0.001$), with priming occurring in the identity condition ($t_1(65) = 16.06$, $p < 0.001$; $t_2(35) = 10.88$, $p < 0.001$) but not the related-binyan condition ($t_1(65) = 0.57$, $p = 0.57$; $t_2(35) = 0.32$, $p = 0.75$). Latencies in the identity condition were significantly shorter than in the related-binyan condition ($t_1(65) = 15.07$, $p < 0.001$; $t_2(35) = 9.82$, $p < 0.001$).

Reaction Time Distributions. The Percentile analysis revealed no significant interaction between percentile and priming condition ($F(8, 910) = 0.50$, $MSE = 11647.02$ sq. ms, $p = 0.86$), suggesting that priming effects were realized as simple shifts of the reaction time distribution. The main effect of priming condition revealed the same pattern of significant differences as in the simple analysis.

Error Rate. The effect of priming condition on error rate was not significant ($F_1(2, 130) = 0.27$, $MSE = 0.0056$ sq. log ms, $p = 0.77$; $F_2(2, 70) = 0.34$, $MSE = 0.00241$ sq. log ms, $p = 0.72$; $\min F'(193) = 0.15$, $p = 0.70$).

Nonword Trials

Mean reaction times, error rates, and outlier rates are given in Table 6. Means and modeled standard errors are plotted in Fig. 1 as well. The identity condition yielded shorter response latencies compared to the related-binyan and unrelated conditions, but these did not differ from each other.

Mean Reaction Time. The overall effect of priming condition was significant ($F_1(2, 130) = 131.13$, $MSE = 0.00362$ sq. log ms, $p < 0.001$; $F_2(2, 69) = 53.67$, $MSE = 0.00491$ sq. log ms, $p < 0.001$; $\min F'(126) = 38.08$, $p < 0.001$), with priming occurring in the identity condition ($t_1(65) = 14.08$, $p < 0.001$; $t_2(35) = 9.38$, $p < 0.001$) but not the related-binyan condition ($t_1(65) = 0.32$, $p = 0.75$; $t_2(34) = 0.26$, $p = 0.79$). Latencies in the identity condition were significantly shorter than in the related-binyan condition ($t_1(65) = 13.01$, $p < 0.001$; $t_2(34) = 7.60$, $p < 0.001$).

Reaction Time Distributions. The Percentile analysis revealed no significant interaction between percentile and priming condition ($F(8, 910) = 0.71$, $MSE = 8661.44$ sq. ms, $p = 0.68$), suggesting that priming effects were realized as simple shifts of the reaction time distribution. The main effect of priming condition revealed the same pattern of significant differences as in the simple analysis.

Error Rate. The overall effect of priming condition on error rate was not significant ($F_1(2, 130) = 0.25$, $MSE = 0.00162$ sq. log ms, $p = 0.78$; $F_2(2, 69) = 0.23$, $MSE = 0.00115$ sq. log ms, $p = 0.79$; $\min F'(176) = 0.12$, $p = 0.73$).

Discussion

Experiment 1b failed to find a facilitatory effect of priming in the related condition, which in this experiment involved prime-target pairs sharing a verbal binyan. Contrary to earlier results reported using the masked visual priming methodology for Hebrew (Deutsch et al., 1998), lexical retrieval of Maltese verbs using supraliminal auditory priming is not facilitated when a target is preceded by a prime in the same binyan. The results of Experiment 1b are also at odds with some results from visual masked priming studies in Arabic (Boudelaa and Marslen-Wilson, 2001b, 2004a,b), where binyan priming has been reported. This is not entirely unexpected, however, given the less reliable nature of binyan priming reported by Boudelaa and Marslen-Wilson (2005), Boudelaa et al. (2010) and Boudelaa and Marslen-Wilson (2011) for Arabic. While the results of Experiment 1b differ from what has been found in the masked visual priming studies in Hebrew and Arabic, they are nonetheless consistent with the results of earlier work in Maltese reported by Twist (2006), in which binyanim failed to facilitate lexical access in a masked visual priming experiment. Whatever phonological and/or morphological relationships exist between words sharing a binyan are not sufficient to yield priming here. Post-hoc analyses distinguishing primes on the basis of phonological overlap with targets (whether primes share zero, one, or both vowels with their respective targets) found no effect for degree of phonological relatedness (see General Discussion).

Experiment 2a

This experiment used pairings of prime and target identical to those used in Experiment 1a, but instead of the supraliminal priming technique used in Experiment 1a, Experiment 2a used the subliminal priming technique. The goal for Experiment 2a was to test the degree to which priming might occur automatically, and whether the consonantal root or the verbal binyan might induce facilitation. Specifically, we were interested in whether we would obtain results analoguous to those reported in the visual masked priming literature on Hebrew and Arabic, as well as to those Twist (2006) previously reported for visual masked priming in Maltese. Experiment 2a utilizes the subliminal speech priming methodology pioneered by Kouider and Dupoux (2005), who showed for native French-speaking subjects that it was possible to obtain identity priming at 35% and 40% compression, despite the fact that their subjects were not consciously aware of the primes at these compression rates. While Kouider and Dupoux (2005) report identity priming at four different durational compression rates, they failed to find any other priming effects at subliminal compression rates (35% and 40%). Though they tested for phonological, morphological, and semantic priming, they did not find that prime-target pairs in these priming conditions manifested any effects of facilitated lexical retrieval. Here, we apply the subliminal speech priming technique to Maltese in order to probe whether identity priming or morphological form priming effects obtain. Given the results of Experiment 1a (roots facilitate lexical access in Maltese) and Experiment 1b (binyanim fail to facilitate lexical access in Maltese) when primes are fully audible, both Experiments 2a and 2b test the same types of morphological priming (root-related priming in Experiment 2a and binyan-related priming in Experiment 2b) when the primes are not consciously perceived by native Maltese-speaking subjects. This technique has now been established to involve processing of primes without conscious awareness, which is why we chose to use it with minimal deviation from the method reported in Kouider and Dupoux (2005). Further exploration of the technique has also been carried out by Schluter (2013), also establishing the subliminal nature of the primes used in the stimuli. As a sanity check, we also included a post-experiment debriefing with each subject, none of whom reported awareness of the primes, in addition to including nonword repetition prime-target pairs. Recall that for Experiments 1a and 1b, a significant repetition priming effect was found for nonword primes paired with identical nonword targets. If no such effect is found for our masked primes in Experiments 2a and 2b, this would confirm lack of conscious awareness of the primes.

Methods

Participants

66 subjects participated in Experiment 2a (28 male subjects, 38 female subjects). The mean age of subjects in Experiment 2a was 29.46 years, and the median age was 21.5 years.

Materials

In Experiment 2a, all prime-target pairs were identical to those used in Experiment 1a. What differed was the nature of the prime: all trials in Experiment 2a involved subliminal primes, following Kouider and Dupoux (2005). The intent here is to find a mode of masked auditory priming analogous to that found in the masked visual priming literature. Subliminal primes are created by durationally compressing the sound file containing a prime to 35% of its original duration using the P(itch) S(ynchronous) O(ver)L(ap) A(dd) algorithm. While such manipulation reduces the duration of the prime to a specified compression rate, pitch remains the same as in the uncompressed version of the prime. The prime is then masked with one preceding (forward) mask and five following (backward) masks. These masks consist of sound files compressed to 35% of their original duration, like the compression applied to the prime, but in addition to being compressed, each mask is also temporally reversed. All primes and masks are amplitude-attenuated (-15dB, following Kouider and Dupoux (2005)). A typical trial consists of one backward mask, followed by the compressed prime, followed simultaneously by the target and the forward masks. A diagram illustrating the components of a typical trial (1 forward mask, 5 backward masks, prime, and target) in Experiments 2a and 2b appears in Fig. 2.[2]

Procedures

Subjects were instructed that they would hear, on each trial, some noise during which there would be something intelligible (the target), which may or may not be a real word of Maltese. The instructions explicitly stated that hearing the intelligible portion might be difficult. Subjects were instructed to perform a lexical decision on the intelligible portion for each trial by pressing the appropriate button on the response box. Other than reference to "noise" in the visually presented instructions, subjects were not given any information about the content of the auditory masks or the compressed prime that accompanied each target. After each experiment, subjects were also given an oral post-experiment debriefing — see the discussion following Experiment 2b for details — where the relevance of the subliminal nature of the primes is raised. Otherwise, all procedures were identical to those in Experiments 1a and 1b.

Results

Table 7: about here

Figure 2: about here

Real Word Trials

Mean reaction times, error rates, and outlier rates are given in Table 7. Means and modeled standard errors are plotted in Fig. 3 as well. The related-root and identity conditions yielded shorter response latencies compared to the unrelated condition, but did not differ from each other.

Mean Reaction Time. The overall effect of priming condition was significant ($F_1(2, 130) =$

[2] Our trials differed from those used in earlier work (Kouider and Dupoux, 2005) in that we added an additional backward mask (for a total of five backward masks following the prime) to ensure that targets of varying length had masking extend beyond the target offset in each trial.

6.86, $MSE = 0.00326$ sq. log ms, $p < 0.005$; $F_2(2,70) = 4.74$, $MSE = 0.00541$ sq. log ms, $p < 0.05$; min$F'(159) = 2.80$, $p < 0.1$), with priming occurring in both the identity condition ($t_1(65) = 2.91$, $p < 0.01$; $t_2(35) = 2.59$, $p < 0.05$) and the related-root condition ($t_1(65) = 3.53$, $p < 0.001$; $t_2(35) = 3.07$, $p < 0.005$). The degree of priming did not differ between these two conditions ($t_1(65) = 0.75$, $p = 0.45$; $t_2(35) = 0.022$, $p = 0.98$).

Reaction Time Distributions. The Percentile analysis revealed no significant interaction between percentile and priming condition ($F(8,909) = 0.45$, $MSE = 14419.63$ sq. ms, $p = 0.89$), suggesting that priming effects were realized as simple shifts of the reaction time distribution. The main effect of priming condition revealed the same pattern of significant differences as in the simple analysis.

Error Rate. The pattern of error rates was similar to that in Exp. 1a, but with reduced magnitudes, such that the overall effect of priming condition did not reach significance ($F_1(2,130) = 1.67$, $MSE = 0.00854$ sq. log ms, $p = 0.19$; $F_2(2,70) = 1.57$, $MSE = 0.00537$ sq. log ms, $p = 0.22$; min$F'(179) = 0.81$, $p = 0.37$).

Nonword Trials

Mean reaction times, error rates, and outlier rates are given in Table 7. Means and modeled standard errors are plotted in Fig. 3 as well. None of the three priming conditions differed from each other.

Mean Reaction Time. The overall effect of priming condition was not significant ($F_1(2,130) = 0.016$, $MSE = 0.00236$ sq. log ms, $p = 0.98$; $F_2(2,70) = 0.0076$, $MSE = 0.00274$ sq. log ms, $p = 0.99$; min$F'(136) = 0.0052$, $p = 0.94$).

Reaction Time Distributions. The Percentile analysis revealed no significant interaction between percentile and priming condition ($F(8,910) = 0.64$, $MSE = 10892.06$ sq. ms, $p = 0.75$), making it unlikely that meaningful differences were hidden by the presence of opposing effects that cancelled each other out. The main effect of priming condition was not significant here either ($F(2,910) = 0.27$, $MSE = 10892.06$ sq. ms, $p = 0.77$).

Error Rate. The overall effect of priming condition on error rate was not significant ($F_1(2,130) = 1.38$, $MSE = 0.00666$ sq. log ms, $p = 0.26$; $F_2(2,70) = 1.16$, $MSE = 0.00427$ sq. log ms, $p = 0.32$; min$F'(172) = 0.63$, $p = 0.43$).

Discussion

Experiment 2a provides evidence for subconscious perception of primes when they are identical to their respective targets, mirroring results reported for French by Kouider and Dupoux (2005). Unlike the French results, our results reveal an additional effect; specifically, prime-target pairs that share a consonantal root revealed facilitated lexical access. As far as we are aware, this is the first non-identity priming effect to be observed with the subliminal speech priming methodology, and is consistent with a degree of automatic subconscious priming for root-related prime-target pairs. As in Experiment 1a, because our control primes were unrelated words, the results of Experiment 2a cannot directly distinguish between morphological and phonological relationships as the source of the priming effect, although post-hoc analyses suggest that phonological priming is not likely to be responsible for this effect (see General Discussion).

These results are consistent with previous work in the visual modality (Twist, 2006) that shows that consonantal roots play a role in lexical access in Maltese.

Experiment 2b

Experiment 2b uses the same subliminal speech priming methodology used in Experiment 2a, but instead of related prime-target pairs sharing a root, in Experiment 2b, related prime-target pairs share a binyan, as in Experiment 1b. Our goal here, similar to Experiment 2a, is to investigate whether the subliminal speech priming methodology will reveal an effect of morphological priming for prime-target pairs sharing a binyan. Recall that Experiment 1b, with supraliminal binyan-related primes, failed to reveal such an effect.

Methods

Participants

70 subjects participated in Experiment 2b (30 male subjects, 40 female subjects). The mean age of subjects in Experiment 2b was 22.98 years, and the median age was 20 years.

Materials

All prime-target pairs in Experiment 2b were identical to those used for Experiment 1b, except that Experiment 2b used the subliminal speech priming methodology.

Procedures

The procedures for Experiment 2b were identical to those for Experiment 2a.

Results

Table 8: about here

Real Word Trials

Mean reaction times, error rates, and outlier rates are given in Table 8. Means and modeled standard errors are plotted in Fig. 3 as well. The identity condition yielded shorter response latencies compared to the related-binyan condition, which in turn had shorter latencies than in the unrelated condition.

Mean Reaction Time. The overall effect of priming condition was significant ($F_1(2, 138) = 13.78$, $MSE = 0.00322$ sq. log ms, $p < 0.001$; $F_2(2, 70) = 8.35$, $MSE = 0.00302$ sq. log ms, $p < 0.001$; $\min F'(152) = 5.20$, $p < 0.05$). Latencies in the identity condition were significantly shorter than in the unrelated condition ($t_1(69) = 4.52$, $p < 0.001$; $t_2(35) = 4.80$, $p < 0.001$). The difference between the related-binyan condition and the unrelated condition was significant in the by-subjects analysis, but not in the by-items analysis ($t_1(69) = 2.14$, $p < 0.05$; $t_2(35) = 1.59$, $p = 0.12$). Latencies in the identity condition were significantly shorter than in the related-binyan condition ($t_1(69) = 3.48$, $p < 0.001$; $t_2(35) = 2.32$, $p < 0.05$).

Reaction Time Distributions. The Percentile analysis revealed no significant interaction between percentile and priming condition ($F(8, 966) = 1.27$, $MSE = 6922.11$ sq. ms, $p = 0.25$), suggesting that priming effects were realized as simple shifts of the reaction time distribution. The main effect of priming condition revealed the same pattern of significant differences as in the simple analysis.

Error Rate. The overall effect of priming condition on error rate was not significant ($F_1(2, 138) = 1.10$, $MSE = 0.00448$ sq. log ms, $p = 0.34$; $F_2(2, 70) = 1.62$, $MSE = 0.00159$ sq. log ms, $p = 0.21$; $\min F'(204) = 0.66$, $p = 0.42$).

Nonword Trials

Mean reaction times, error rates, and outlier rates are given in Table 8. Means and modeled standard errors are plotted in Fig. 3 as well. None of the three priming conditions differed from each other.

Mean Reaction Time. The overall effect of priming condition was not significant ($F_1(2, 138) = 0.40$, $MSE = 0.00244$ sq. log ms, $p = 0.67$; $F_2(2, 69) = 0.57$, $MSE = 0.00317$ sq. log ms, $p = 0.57$; $\min F'(201) = 0.24$, $p = 0.63$).

Reaction Time Distributions. The Percentile analysis revealed no significant interaction between percentile and priming condition ($F(8, 963) = 0.51$, $MSE = 6079.23$ sq. ms, $p = 0.85$), making it unlikely that meaningful differences were hidden by the presence of opposing effects that cancelled each other out. The main effect of priming condition was not significant here either ($F(2, 963) = 1.02$, $MSE = 6079.23$ sq. ms, $p = 0.36$).

Error Rate. The overall effect of priming condition on error rate was not significant ($F_1(2, 138) = 0.057$, $MSE = 0.00487$ sq. log ms, $p = 0.94$; $F_2(2, 69) = 0.026$, $MSE = 0.00334$ sq. log ms, $p = 0.97$; $\min F'(133) = 0.018$, $p = 0.89$).

Discussion

Experiment 2b revealed only an identity priming effect, which was also found in Experiment 2a. Experiment 2b failed to find a clear effect of priming for prime-target pairs sharing a binyan when the prime is presented subliminally. Although reaction times in the related-binyan condition differed significantly from the unrelated condition in the by-subjects analysis, they did not differ in the by-items analysis, and moreover were significantly longer than the times in the identity condition, in contrast to Experiment 2a. Together with the fact that in all other cases in this set of experiments, subliminal priming effects are weaker than the analogous audible priming effect, this pattern suggests that the significant effect in the by-subjects analysis is a Type I Error, and whatever phonological and/or morphological relationships exist between words sharing a binyan are not sufficient to yield priming here. Additionally, no significant effect was found for the related Binyan condition in the alternative mixed model in Appendix 2. Post-hoc analyses distinguishing primes on the basis of phonological overlap with targets (whether primes share zero, one, or both vowels with their respective targets) found no effect for degree of phonological relatedness (see General Discussion).

Figure 3: about here

These results provide both off-line and on-line evidence supporting the conclusion that the subliminal speech priming technique used in Experiments 2a and 2b is indeed subliminal - that is, subjects did not consciously perceive the primes - and can therefore be considered a reliable auditory analog of visual masked priming. Post-experiment debriefing of all subjects following Experiments 2a and 2b indicated that subjects in these experiments were not consciously aware of the subliminal primes. When asked to describe the "noise" that contained the masks as well as the compressed prime, some subjects described it as sounding like a foreign language; a subset of these subjects "identified" the noise as Chinese. Subjects also uniformly reported an explicit strategy of not paying attention to the "noise" in each trial in order to be able to perform at higher accuracy on the lexical decision task. Further, within the reaction time data we also find evidence consistent with the notion that compressed primes were subliminal: in the supraliminal experiments (Experiments 1a and 1b), non-word prime-target pairs showed strong identity priming (Fig. 4), i.e., it was easier for subjects to reject a nonword target when preceded by the same nonword. However, no such facilitation for identical nonword prime-target pairs was found in the subliminal experiments (Experiments 2a and 2b), suggesting that subjects did not consciously perceive the primes.

Figure 4: about here

General Discussion

The results of these four experiments are consistent the hypothesis that Maltese lexical access is facilitated by the consonantal root, and therefore provide support to models of spoken word processing that require or allow morphological decomposition (Balling and Baayen, 2008; Marslen-Wilson et al., 1994; Meunier and Segui, 1999; Schriefers et al., 1991; Taft et al., 1986; Wurm, 1997, 2000). These models all share the property of abstract, morphological structure, and support the inclusion of the morpheme as a crucial component of lexical entries. In the experiments reported here, priming when roots were shared was found with both audible and subliminal primes, indicating that root-associated material is implicated in the early, automatic processing of spoken words in Maltese. We take this as evidence that the root is part of the lexical entry for Semitic words in Maltese, in line with the models cited above that provide a parsing route for morphologically complex words. This is also consistent with models based on previous evidence for root-priming found in Hebrew (Deutsch et al., 1998; Frost et al., 1997) and Arabic (Boudelaa and Marslen-Wilson, 2001b, 2004a) in the visual modality. While these previous studies were carried out using orthographically presented stimuli in languages with consonantal writing systems, we used two complementary strategies to further reduce potential links between orthography and morphology. First, our studies were carried out in Maltese, a language with qualitatively less orthographic support for root-and-pattern morphological decomposition. Second, our methodology included masked and non-masked auditory priming to further minimize orthographic influence.

More work is needed in order to test the possibility that other priming types could be responsible for the effects of root-based morphological priming we report here. One possibility is that these effects are driven not solely by morphological priming, but also by semantic priming. While semantics has been shown to affect lexical access in a non-priming lexical decision task in Hebrew (Moscoso del Prado Martín et al., 2005), semantics appears not to affect morphological priming. Work in the visual domain in Hebrew by Frost et al. (1997) suggests that semantic relatedness does not confer a processing advantage above and beyond that conferred by morphological relatedness. Those studies used an SOA of 43 ms, which is typically too small an SOA to induce an effect of semantic relatedness. Semantic effects can be found at much longer SOAs as in Frost and Bentin (1992) but as reviewed in Feldman (2000), under conditions in which processing time is kept intentionally short, "effects of semantic relatedness are generally absent." Further, morphological relatedness primes in the absence of semantic relatedness: the results reported in Experiment 5 by Frost et al. (1997) for Hebrew show that facilitatory priming is obtained when prime-target pairs are morphologically but not semantically related (e.g., prime = *meragel* 'spy', target = *targil* 'exercise'). Our prime-target pairs in Maltese were not selected based on degree of semantic relatedness.

It is also in principle possible that phonological priming accounts for or contributes to the priming effects found in the shared root conditions of Experiments 1a and 2a. We have several indirect reasons for thinking phonological priming is unlikely to account for this effect to the exclusion of morphological priming, and we are currently directly testing this hypothesis (see below). We note that previous work using masked auditory primes in French found no evidence for phonological priming (Kouider and Dupoux, 2005). Further, the complete lack of priming in the non-word condition in all subliminal experiments again suggests that phonological relatedness may not speed lexical search under these conditions. Finally, we attempted post-hoc analyses to test whether degree of phonological relatedness in the root conditions might affect priming. In Experiments 1a and 2a, where prime-target pairs in the related condition shared a consonantal root, we classed all pairs according to whether the prime item contains the target item. For approximately one third of the root-related prime-target pairs, the prime differs from the target by solely by prefixation of a consonant. For these prime-target pairs, the prime is nearly identical to the target. In the other two-thirds of the prime-target pairs, the prime differs from the target in addition by vowel identity and/or presence of medial consonant gemination. No significant difference was found between prime-target pairs that exhibit such a containment relationship vs. pairs that do not; both types yield significant priming compared to pairs in the control condition (see Appendix 2 for the details of post-hoc mixed effects model analyses). However, due to the small sample size this lack of a significant difference cannot be taken to rule out phonological priming. We note, however, that the split Semitic/Indo-European lexicon of Maltese provides an unusual way to test for phonological priming on the basis of shared consonants. Experiments are currently being carried out that use lexical items from the Indo-European stratum of Maltese as primes that happen to contain the same consonants as a Semitic target (e.g., *klima* 'climate' paired with *kelma* 'word').

The effects of priming between prime-target pairs sharing a consonantal root found in Experiments 1a and 2a are consistent with the results from visual masked priming reported by Twist (2006), who found the identical pattern of effects in Maltese. Also similar to Twist's results, but at odds with earlier work in the masked visual domain for other Semitic languages like Hebrew and Arabic, is the lack of any facilitatory effect for binyanim or word patterns. Twist (2006) failed to find an effect of word pattern for Maltese verbs, but earlier work in Hebrew (Deutsch et al., 1998) and Arabic (Boudelaa and Marslen-Wilson, 2001b, 2004a, 2005) finds some evidence that the word pattern facilitates lexical access in those languages in the visual modality, though this effect is considerably more fragile than root priming. In our studies, binyan priming was not found with either auditory or masked primes. The information content of many word patterns may simply be too low to cross a threshold of activation allowing them to serve as a route for lexical retrieval. Word patterns are functional elements, and as such their information content is relatively low; each word pattern in general defines a large class of words. In contrast, roots are lexical and provide relatively more information. Experiments are currently underway to compare priming by more/less lexically informative word patterns in Maltese.

Acknowledgments

The authors wish to thank the following individuals and institutions for their support and expertise: Dan Brenner, Dr. Ray Fabri, Dr. Albert Gatt, Luke Galea, Dr. Scott Jackson, Dr. Amy LaCross, and the Institute of Linguistics at the University of Malta. Additionally, we thank our associate editor, Dr. Elisabeth Norcliffe, as well as three reviewers, for all of their feedback and suggestions.

Funding

This material is based upon work supported by the National Science Foundation [BCS-0715500] to Adam Ussishkin. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Appendix 1. Stimulus Lists

Sound files used as stimuli can be found online at the open-access University of Arizona Campus Repository. Stimuli used in Experiments 1a and 1b (those with audible primes) can be found at http://hdl.handle.net/10150/300383 and stimuli used in Experiments 2a and 2b (those with subliminal primes) can be found at http://hdl.handle.net/10150/300384.

Table A1. Root Priming Stimuli - Experiments 1a and 2a

Real Word Target	**Root**	**Control**	**Nonword Target**	**Root**	**Control**
sikket	siket	qomos	gemmeħ	gemeħ	biraġ
kiber	tkabbar	iġġissem	liħeb	tliħħeb	tgezzaħ
tqarras	qaras	romol	tqarram	qirim	ħalap
ħareġ	nħareġ	nqatel	qiħal	nqiħal	mmereħ
nqabad	qabad	meraħ	nnakam	nakam	masag
ġenneb	iġġenneb	tqammel	qemmal	tqemmal	tmarraf
tbikkem	bikkem	nemmes	tkellef	kellef	ħozzak
beżżaq	nbeżaq	ngiref	qimmas	nqimas	nġigef
ntelaq	tellaq	naġġar	nqadar	qaddar	birraq
tħalleb	nħaleb	ndiehex	ssittar	nsitar	nġanab
nfetaħ	tfettaħ	tniffes	nrataħ	trattaħ	tpiħħel
tama’	tamma’	ċekken	kabaf	kabbaf	zaħħap
laqqat	laqat	seraq	ħennap	ħenap	ġasam
nixef	tnixxef	tbewwes	ħineq	tħennaq	żżarreg
tħasseb	ħaseb	kines	ċċimmeħ	ċimeħ	żagam
xeħet	nxeħet	nħakem	qoroħ	nqiraħ	mmagaż
ndifen	difen	nibet	nħazap	ħezop	fiħer
ħammeġ	tħammeġ	tkerrah	qaffal	tqeffel	tleqqet
tħemmed	ħemmed	berraq	tgaħħal	gaħħal	messer
giddem	ngidem	ntasab	qemmeċ	nqemeċ	mmiqeż
ngirex	gerrex	redden	nkeħaċ	keħħaċ	ħommaġ
tferrex	nfirex	nħalaq	tqezzeħ	nqezeħ	nżareq
ndarab	iddarrab	iċċappas	nċemeg	ċċemmeg	tqesseq
raqad	raqqad	baħħar	nikib	nikkib	ħaġġaq
naqqas	naqas	sibel	qiffiċ	qifiċ	benot
nebaħ	tnebbaħ	tfaqqar	faġaq	tfaġġaq	zzaħħam
iżżellaq	żelaq	barax	tqaffan	qafan	bużeq
ħonoq	nħonoq	ntefaħ	ħaras	nħiras	ngafen
nqafel	qafel	fileġ	nbeles	bilas	nifal
fakkar	tfakkar	tħabat	labbaf	tlabbaf	tqirras
tfaħħar	faħħar	ħarref	tmeħħer	meħħer	qimmiġ
tallab	ntalab	nħatar	temmar	ntamar	nħipel
nfaġar	faġġar	baqqan	nħeper	ħeppor	zekkeħ
tfettaq	nfetaq	nsaram	tpolloħ	npoloħ	nżigag
nħadem	tħaddem	ittaqqab	nrakat	trakkat	tħilleg

Table A2. Binyan Priming Stimuli - Experiments 1b and 2b

Real Word Target	**Binyan**	**Control**	**Nonword Target**	**Binyan**	**Control**
siket	kiber	xebbah	nikib	qifiċ	limmaq
bikkem	ħammeġ	deher	feqqoċ	ġappaħ	ċiħap
sibel	qomos	iġġiddem	benot	meser	trelleb
tfaħħar	tbattal	żehel	tpolloħ	tkekkem	żenad
nibet	seraq	ntasab	gemeħ	ħenap	nħazab
nħareġ	ndiehex	naħar	nsitar	nġanab	gareż
berraq	ħemmed	ixxellef	birraġ	ġassam	tħilleċ
tniffes	tfakkar	ħaxxen	trakkat	tqaddar	kammad
nemmes	ġenneb	nġabar	demmos	kabbaf	nqiraħ
ntelaq	nqabad	berren	nnakam	nrataħ	gonnaħ
iċċaħħad	iġġissem	ntalab	tgezzaħ	żżarreg	nkeħaċ
nfetaħ	nbeżaq	tqaċċat	nċemeg	nqezeħ	tbiġġel
laqat	darab	mellaħ	biraq	ħomaġ	qallaf
naġġar	xettel	kesaħ	zekkeħ	ħimmid	neħep
nixef	raqad	issaħħar	zaħap	qiliħ	tħennaq
tqammel	tħabat	rikeb	tliħħeb	tħilleg	ħotal
meraħ	tama'	nħatar	qimiġ	giċaf	ngodom
nħaleb	ngirex	niseġ	nzaħam	nripaħ	ċalaq
faqqar	ċappas	issaħħab	baħħaġ	ħaġġaq	ċċakkaf
ittaqqab	tnikket	nemmex	tpiħħel	tqesseq	falleġ
ħarref	żeggeg	ndilek	ħozzak	bakkam	nqefel
ndifen	nfileg	xekkel	nżareq	nnimaħ	rabbam
tfattar	tbewwes	nħakem	tqimmas	tkoffoċ	nħilat
nqaras	nxeħet	issammar	nqiħal	nżigag	tfarraq
fileġ	ħabat	sakkar	rifig	żagam	kirref
baqqan	rattab	resaq	bużżeq	goddal	ċetar
feraq	sebaħ	tnaffar	qeber	mireg	tmiħħat
issabbar	tħaddet	naħaq	tmiqqiż	tqemmal	baħan
naqas	ħalef	nżarad	nifal	ħalap	mmasaq
ngidem	nfaġar	ħamel	mmaraf	ngafen	qaħaċ
ċekken	baħħar	issaffar	fitter	gażżam	tmaggas
tkittef	tħallat	ċallas	tgaħħam	ġġiggef	ġaqqef
redden	ħasseb	ngiref	massag	fiħħer	nħidet
nqafel	nsaram	ħarrek	nraħag	mmereħ	lesson
tkerrah	tlissen	ntilef	tqirras	tleqqet	nħazap
nħonoq	nfirex	iġġarraf	mmagaż	nnasar	tqemmeċ

Appendix 2. Mixed Effects Analyses

Log reaction times were analyzed using a linear mixed effects model, fit using the `lmer` package in R. Priming Condition and Trial Number were included as fixed effects, with the latter included only to reduce serial correlation in the residuals. For the real-word data from Exps. 1a and 2a, related-root trials were subdivided according to whether the prime word contained the target word, resulting in four levels of Priming Condition in the full model (identity, related-contained, related-not-contained, and unrelated). The containment distinciton was intended as a measure of phonological relatedness in order to tease apart morphological and phonological priming effects. Similarly, for the word data in Exps. 1b and 2b, the related-binyan trials were subdivided according to the number of vowels shared between the target and prime (0, 1 or 2), resulting in a total of 5 levels of Priming Condition (identity, related-0, related-1, related-2, and unrelated).

Priming Condition was treatment-coded with the unrelated condition as the reference. Trial Number was initially coded as an orthonormal quadratic polynomial, but this led to convergence failures for some datasets, and so the quadratic term was dropped from all models for consistency. The full random-effects structure was used: At the Subject level, random intercepts, random slopes for both Priming Condition and Trial, and all correlation parameters were estimated. At the Target Item level, random intercepts, random slopes for Priming Condition, and all correlation parameters were estimated.

The distributions of the residuals are plotted by experiment and lexical status in Fig. 5, along with a reference Normal distribution. There do not appear to be any serious violations of the Normality assumption. There was also no serious issue with collinearity of the fixed effects: Pairwise correlations $|r| < 0.5$ for all pairs of coefficients, except for the related vs. unrelated and identity vs. unrelated contrasts, which had correlations between 0.50 and 0.63 in the nonword model in Exp. 2a, and for both words and nonwords in Exp. 2a. Although these correlations are subsantial, they are not surprising given that the two contrasts in question involve a common reference condition.

The results of Likelihood Ratio tests with nested model comparison for individual fixed effects and groups of fixed effects are shown in Table A3. The distinction between related root trials in which the target was contained by the prime and those in which it was not did not yield significant differences in the degree of priming for either experiment 1a or 2a, as revealed by a likelihood ratio test against a model without the subdivision between contained and non-contained targets. Similarly, for the related-binyan trials, the number of shared vowels between target and prime did not yield any significant difference in priming. The remaining results corroborate the ANOVA results reported above. When primes were audible, significant priming effects obtained for identity primes in all experiments, for both words and nonwords, but morphologically related primes only yielded a significant reaction time reduction when the root was shared. When primes were subliminal, the same pattern held for real words, but no priming whatsoever occurred for nonwords.

Table A3. Mixed Effects Model Likelihood Ratio Test results by experiment, lexicality and contrast.

Experiment	Lexicality	Contrast	df	χ^2	p	
Exp 1a	Words	Overall	3	68.04	<0.001	*
		Id. vs. Unrel.	1	67.13	<0.001	*
		Rel. vs. Unrel.	2	49.41	<0.001	*
		Containment	1	0.54	0.46	
	Nonwords	Overall	2	75.32	<0.001	*
		Id vs. Unrel.	1	72.55	<0.001	*
		Rel. vs. Unrel.	1	0.00	1.00	
Exp 1b	Words	Overall	4	71.33	<0.001	*
		Id. vs. Unrel	1	64.48	<0.001	*
		Rel. vs. Unrel.	3	2.14	0.54	
		Vowel Overlap	2	1.56	0.46	
	Nonwords	Overall	2	85.79	<0.001	*
		Id. vs. Unrel.	1	83.12	<0.001	*
		Rel. vs. Unrel.	1	1.12	0.29	
Exp 2a	Words	Overall	3	16.03	0.0011	*
		Id. vs. Unrel.	1	11.04	<0.001	*
		Rel. vs. Unrel.	2	13.84	<0.001	*
		Containment	1	1.13	0.29	
	Nonwords	Overall	2	0.00	1.00	
Exp 2b	Words	Overall	4	23.26	<0.001	*
		Id. vs. Unrel	1	20.32	<0.001	*
		Rel. vs. Unrel.	3	4.02	0.26	
		Vowel Overlap	2	0.98	0.61	
	Nonwords	Overall	2	2.34	0.31	

Figure 5: about here

Tables

Table 1. Partial Maltese paradigm for root /ktb/, adapted from Spagnol (2011)

Word pattern	**Maltese word**	**Gloss**
$C_1VC_2VC_3$	kiteb	*he wrote*
$C_1VC_2C_2VVC_3$	kittieb	*writer*
$C_1VC_2C_3V$	kitba	*writing*
$nC_1VC_2VC_3$	nkiteb	*it was written*
$mVC_1C_2CV_3$	miktub	*written*
$C_1C_2VVC_3$	ktieb	*book*
$C_1C_2VjjVC_3$	ktejjeb	*booklet*

Table 2. Maltese binyanim, adapted from Twist (2006)

Binyan	**Function**	**Example**
1 ($C_1VC_2VC_3$)	basic active (transitive or intransitive)	kiser *'to break'*
2 ($C_1VC_2C_2VC_3$)	intensive of 1, transitive of 1	kisser *'to smash'*
3 ($C_1ieC_2VC_3$)	transitive of 1	bierek *'to bless'*
5 ($tC_1VC_2C_2VC_3$)	passive of 2, reflexive of 2	tkisser *'to get smashed'*
6 ($tC_1ieC_2VC_3$)	passive of 2, reflexive of 3	tkieteb *'to correspond'*
7 ($nC_1VC_2VC_3$)	passive of 1, reflexive of 1	nkiser *'to get broken'*
8 ($C_1tVC_2VC_3$)	passive of 1, reflexive of 1	ftakar *'to remember'*
9 ($C_1C_2VVC_3$)	inchoative, acquisition of a quality	ħmar *'to blush'*
10 ($stVC_1C_2VC_3$)	originally inchoative	stenbah *'to awake'*
Q1 ($C_1VC_2C_2VC_3$)	basic active	ħarbat *'to ruin'*
Q2 ($tC_1VC_2C_2VC_3$)	passive and/or reflexive of Q1	tħarbat *'to be ruined'*

Table 3. Sample Primes and Targets for Exp 1a.

	Priming Condition		
	Identity	*Root-Related*	*Unrelated*
Prime	giddem 'to gnaw'	ngidem 'to be bitten'	ntasab 'to take a seated position'
Target	giddem 'to gnaw'	giddem 'to gnaw'	giddem 'to gnaw'

Table 4. Reaction times (ms) by lexicality and priming condition, Exp. 1a

Exp. 1a	Mean	95% CI		Errors	Outliers	Total Excluded
Words						
Ident.	892	841	946	10.42	2.09	12.13
Rel.	915	867	964	8.09	2.45	9.93
Unrel.	1047	988	1109	11.64	3.06	13.85
Nonwords						
Ident.	935	885	988	6.99	2.70	8.96
Rel.	1118	1063	1177	15.20	2.45	17.52
Unrel.	1112	1060	1166	7.84	2.70	10.42

Table 5. Sample Primes and Targets for Exp 1b.

	Priming Condition		
	Identity	*Binyan-Related*	*Unrelated*
Prime	siket 'to be quiet'	kiber 'to grow'	xebbah 'to assimilate'
Target	siket 'to be quiet'	siket 'to be quiet'	siket 'to be quiet'

Table 6. Reaction times (ms) by lexicality and priming condition, Exp. 1b

Exp. 1b	Mean	95% CI		Errors	Outliers	Total Excluded
Words						
Ident.	887	845	931	7.45	2.53	9.47
Rel.	1047	999	1096	6.57	3.03	9.34
Unrel.	1052	1006	1100	6.57	2.78	8.84
Nonwords						
Ident.	912	870	955	2.27	2.02	4.17
Rel.	1058	1015	1103	2.86	2.47	4.94
Unrel.	1066	1024	1110	2.46	2.70	4.67

Table 7. Reaction times (ms) by lexicality and priming condition, Exp. 2a

Exp. 2a	Mean	95% CI		Errors	Outliers	Total Excluded
Words						
Ident.	959	909	1012	10.51	2.78	12.78
Rel.	955	901	1012	10.89	2.66	13.29
Unrel.	996	939	1058	13.26	2.65	15.53
Nonwords						
Ident.	1076	1024	1131	12.12	1.90	13.53
Rel.	1079	1028	1133	10.37	2.40	11.88
Unrel.	1078	1023	1136	10.24	2.02	11.76

Table 8. Reaction times (ms) by lexicality and priming condition, Exp. 2b

Exp. 2b	Mean	95% CI		Errors	Outliers	Total Excluded
Words						
Ident.	901	864	939	6.31	2.02	7.86
Rel.	931	895	969	7.02	2.86	9.52
Unrel.	950	910	992	7.74	2.02	9.52
Nonwords						
Ident.	997	957	1039	6.55	3.93	9.88
Rel.	1003	962	1046	6.48	2.81	8.68
Unrel.	1009	968	1052	7.19	3.02	9.16

Table 9. Reaction times (ms), error rates (%) and outlier rates (%) by priming condition

	Mean	95% CI		Errors	Outliers	Total Excluded
Exp 1a, Words						
Ident.	892	841	946	10.42	2.09	12.13
Rel.	915	867	964	8.09	2.45	9.93
Unrel.	1047	988	1109	11.64	3.06	13.85
Exp 1a, Nonwords						
Ident.	935	885	988	6.99	2.70	8.96
Rel.	1118	1063	1177	15.20	2.45	17.52
Unrel.	1112	1060	1166	7.84	2.70	10.42
Exp 1b, Words						
Ident.	887	845	931	7.45	2.53	9.47
Rel.	1047	999	1096	6.57	3.03	9.34
Unrel.	1052	1006	1100	6.57	2.78	8.84
Exp 1b, Nonwords						
Ident.	912	870	955	2.27	2.02	4.17
Rel.	1058	1015	1103	2.86	2.47	4.94
Unrel.	1066	1024	1110	2.46	2.70	4.67
Exp 2a, Words						
Ident.	959	909	1012	10.51	2.78	12.78
Rel.	955	901	1012	10.89	2.66	13.29
Unrel.	996	939	1058	13.26	2.65	15.53
Exp 2a, Nonwords						
Ident.	1076	1024	1131	12.12	1.90	13.53
Rel.	1079	1028	1133	10.37	2.40	11.88
Unrel.	1078	1023	1136	10.24	2.02	11.76
Exp 2b, Words						
Ident.	901	864	939	6.31	2.02	7.86
Rel.	931	895	969	7.02	2.86	9.52
Unrel.	950	910	992	7.74	2.02	9.52
Exp 2b, Nonwords						
Ident.	997	957	1039	6.55	3.93	9.88
Rel.	1003	962	1046	6.48	2.81	8.68
Unrel.	1009	968	1052	7.19	3.02	9.16

Figures

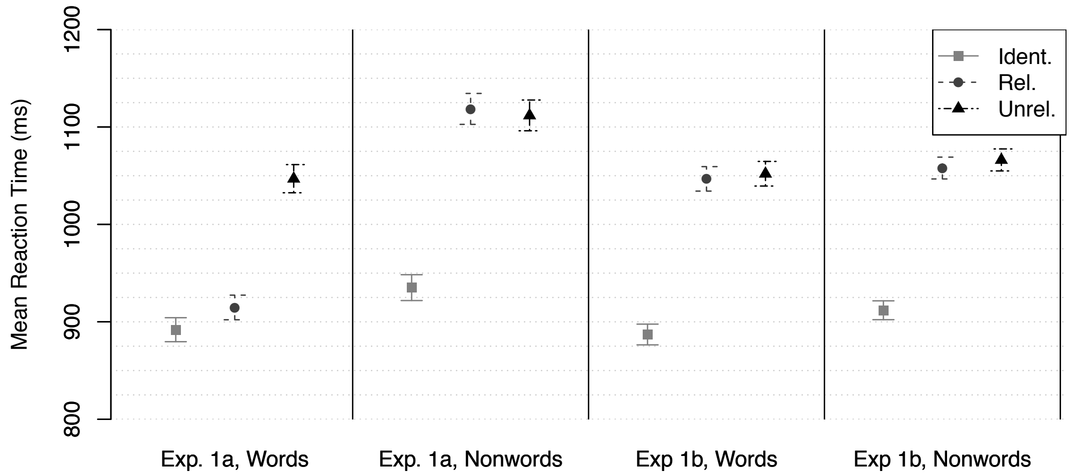

Figure 1. Mean Log Reaction Times transformed back to the ms scale, Exps. 1a-b. Error bars represent $\pm$ 1 *SE* of pairwise differences between conditions, as computed on the log scale.

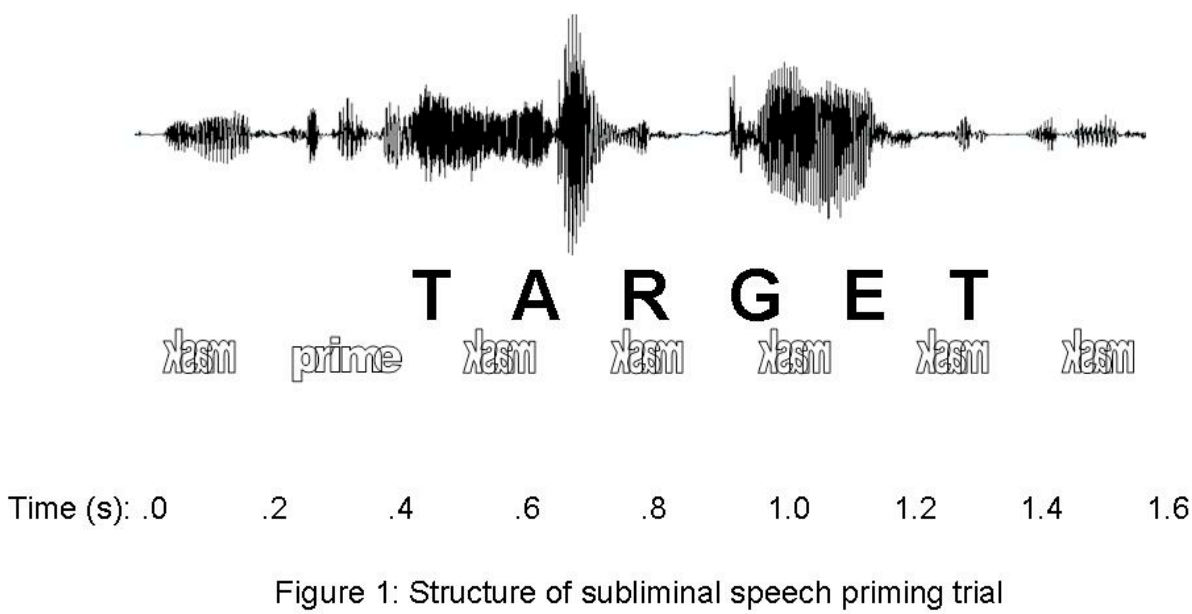

Figure 2. Diagram of trial components in Experiments 2a and 2b; the word "mask" occurs in reverse and with small font spacing to visually represent that each mask is auditorily reversed and durationally compressed; the word "prime" occurs with small font spacing to visually represent that it is durationally compressed.

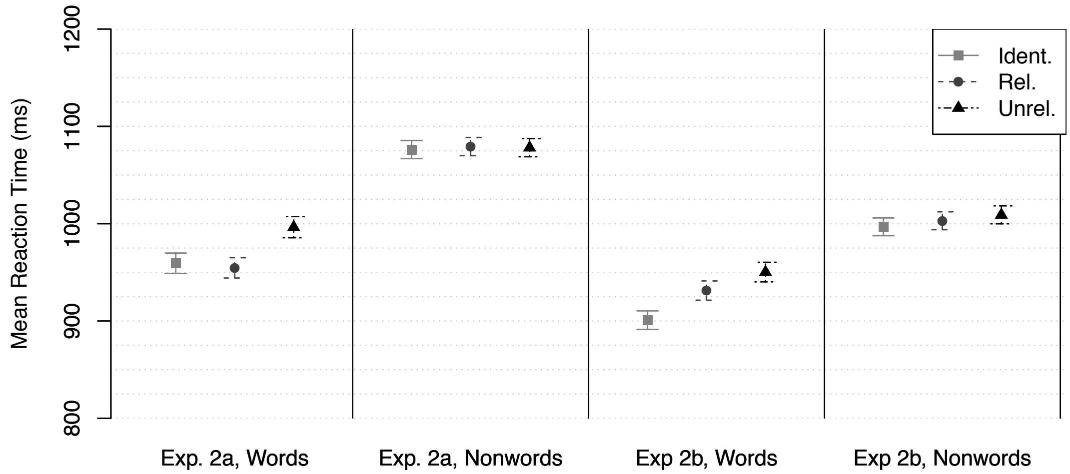

Figure 3. Mean Log Reaction Times transformed back to the ms scale, Exps. 2a-b. Error bars represent ± 1 *SE* of pairwise differences between conditions, as computed on the log scale.

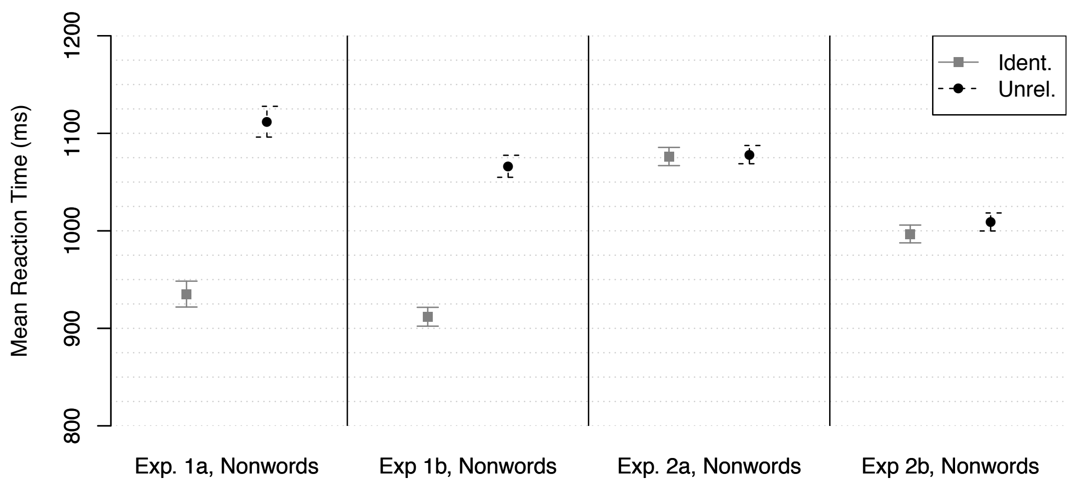

Figure 4. Mean Log Reaction Times transformed back to the ms scale, Nonword Trials, Identity vs. Unrelated Conditions. Error bars represent ± 1 *SE* of pairwise differences between conditions, as computed on the log scale.

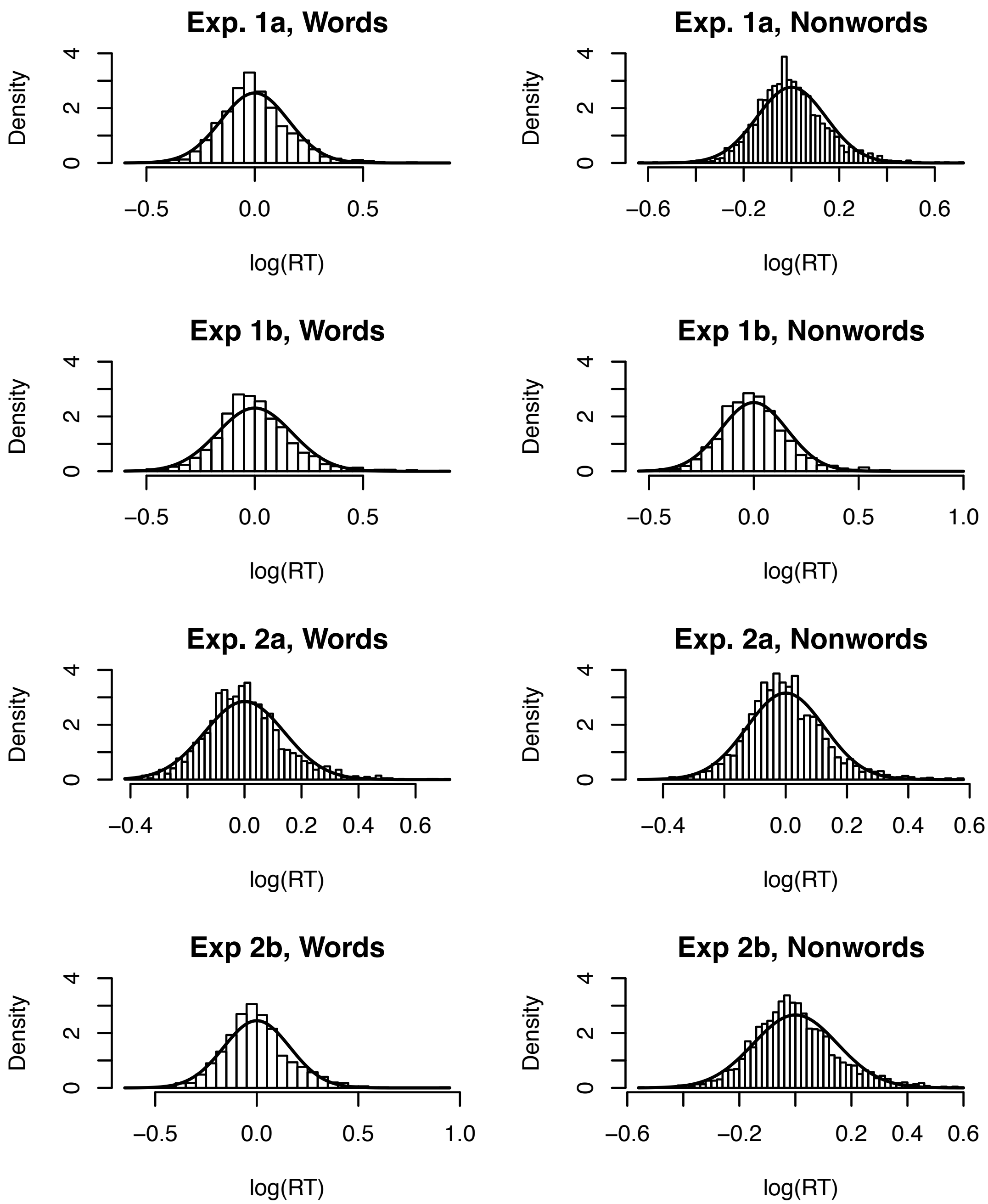

Figure 5. Distributions of model residuals by experiment and lexicality. The solid curve is a reference normal distribution.