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Priming stress patterns in word recognition

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Abstract

This study addresses the lexical representation of stress in a series of five intra-modal and cross-modal priming experiments in the Greek language using lexical decision tasks with auditory and visual targets. Three-syllable primes and targets were matched in first syllable segments, length, and other variables, and differed segmentally in the second and third syllable. Primes matched or mismatched targets in stress, which was placed on the penultimate or antepenultimate syllable. There was no evidence for stress priming in either accuracy or latency of responses to either words or pseudowords in any of these experiments, either intra-modally or cross-modally. In contrast, a control fragment priming experiment using only the first two syllables of the primes produced a significant effect of stress congruence for words but not for pseudowords. The results are interpreted in the context of previous findings in the literature as arising from lexical activation rather than from matching stress patterns. Overall, findings are consistent with lexical representations including stress information that is inseparable from segmental specification, rather than with abstract representations of metrical templates.

Keywords: lexical stress; stress priming; visual word recognition; spoken word recognition; lexical decision; Greek

Priming stress patterns in word recognition

In this study we are concerned with the representation of lexical stress and its activation during word recognition. Lexical stress is part of the metrical representation of words, corresponding to relative prominence among syllables: Simplifying somewhat, a prominent syllable is *stressed* in contrast to other syllables that are *unstressed*. In languages said to have free stress, that is, languages in which the position of stress can vary, stress can distinguish word meaning. For example, in English, the verb "to pro<u>test</u>" is distinguished from the noun "<u>pro</u>test" by the location of stress (indicated by underlining): on the second syllable in the verb but on the first syllable in the noun. Stress is an abstract phonological property of lexical items that is systematically associated with acoustic features in spoken words. Specifically, the phonetic correlates of stress typically include increased amplitude and duration (Beckman, 1986; Laver, 1994). Stress is also associated with variations in pitch, depending on the intonational and phrasal context (Ladd, 2008, ch. 2), and with differences in vowel quality (Beckman, 1986; Beckman & Edwards, 1994).

In English, vowel quality is a major phonetic determinant of stress insofar as stressed syllables contain full vowels whereas reduced vowels occupy unstressed syllables.[1] Because of this confound between stress and segmental cues in English it is not possible to investigate stress effects independently of segmental representations: Unreduced realization of unstressed syllables is unnatural in all but a few atypical words, adversely affecting the interpretability and generalizability of findings (see discussions in Cooper, Cutler, & Wales, 2002; Cutler & van Donselaar, 2001). Therefore

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[1] Distinctions based on vowel quality, rather than syllabic prominence, have been termed "metrical stress," to contrast with "lexical stress" (e.g., Slowiaczek, Soltano, & Bernstein, 2006). This distinction is largely specific to English and will not be pursued further in the present report.

our discussion of English in this manuscript will be limited to mentioning relevant findings with the understanding that no cross-linguistic generalization can be based on studies in English. In other European languages, such as Spanish (Ortega-Llebaria & Prieto, 2007) and Greek (Arvaniti, 2007; Fourakis, Botinis & Katsaiti, 1999), stress is only weakly associated with segmental quality. This permits manipulation of stress patterns independently of segmental constituency to uncover effects specific to stress, as we attempt to do in this study in the Greek language.

Several studies suggest that stress contributes to lexical disambiguation. Much of this evidence is based on work with word fragment priming. Soto-Faraco, Sebastian-Gallés, and Cutler (2001) showed that in Spanish lexical decisions were facilitated for words preceded by stress-congruent primes (syllable pairs) and inhibited for words preceded by stress-incongruent primes. For example, the printed word “príncipe” (prince) was recognized faster following the auditory fragment /prinθi/ (stressed on the first syllable, consistent with the word) than following the fragment /prinθi/ (taken from the word “principio”, stressed on the second syllable). Similar findings (of facilitation; but not always of inhibition) were subsequently reported for Dutch (van Donselaar, Koster, & Cutler, 2005), Italian (Tagliapietra & Tabossi, 2005) and English (Cooper et al., 2002). Collectively, these studies have confirmed psycholinguistically that representations in the mental lexicon are contrasted by stress patterns, as expected from linguistic analysis.

More recent studies have employed eye tracking to examine the time course of stress influences on lexical segmentation and lexical access. In a variant of the visual world paradigm with printed word targets, Reinisch, Jesse, and McQueen (2009) showed that Dutch lexical selection is constrained as soon as acoustic information indicating a stressed syllable becomes available. Participants looked at the word "octopus" significantly more than at "oktober" immediately after the stressed initial vowel of /okto/ (from octopus) had been heard. Looking more at "oktober" occurred after hearing both syllables of /okto/ (from oktober), to include the stressed second syllable. Similar findings have been reported in Italian (Sulpizio & McQueen, 2012). More recently, Jesse and McQueen (2014) found that stress information need not be auditory, because seeing a speaker utter the disambiguating fragments sufficed to bias looking toward the stress-matching target.

In a similar vein, studies have used event-related potentials (ERP) in the context of fragment priming to examine the uptake of prosodic features related to stress in German. Friedrich, Kotz, Friederici, and Alter (2004) found that auditory monosyllabic fragments with fundamental frequency (F_0) contours derived from stressed or unstressed syllables affected response times and ERP components to subsequent visual word targets. Follow-up studies also reported ERP effects of prosodic congruence with monosyllabic primes in certain time windows (with inconsistencies in effect polarity and in behavioral response times; Schild, Becker, & Friedrich, 2014a,b). These findings must be interpreted in the context of studies demonstrating elicitation of ERP components by metrical shifts or violations in German and other languages (Domahs, Knaus, El Shanawany, & Wiese, 2014; Knaus, Wiese, & Janßen, 2007; Rothermich, Schmidt-Kassow, Schwartze, & Kotz, 2010; Schmidt-Kassow, & Kotz, 2009; Schmidt-Kassow, Roncaglia-Denissen, & Kotz, 2011), confirming the online perceptual sensitivity to prosodic information associated with stress differences. Notably, perceptual interpretation of prosodic acoustic cues in terms of stress depends on local phrasal context (in English; Brown et al., in press).

Overall, these studies are consistent with the idea that stress-related acoustic properties are used to constrain lexical activation. This might be achieved in two ways (cf. Schild et al., 2014a): One option would involve stress patterns as distinct metrical representations associated with entries in the mental lexicon. Comparable metrical representations would be computable from the input, independent of segmental representations. Stress patterns arising from incoming prosodic cues would match or mismatch the lexically stored patterns and thereby facilitate or inhibit lexical activation. In this conceptualization stress representations are abstract in the sense that they can stand on their own, to be computed and compared regardless (or in the absence) of specific lexical items. An alternative option would involve mapping of prosodic properties directly onto lexical representations, in the sense of systematic phonetic or subphonetic variability.[2] In this case, for example, a lexical item with an initial stressed syllable would be a better match for an incoming long and loud syllable than items with initial unstressed syllables. In this alternative conceptualization, lexical entries must contain specification of stress-relevant prosodic properties, to allow matching with corresponding input cues, and stress representations are not abstracted away from lexical or input representations.

By definition, stress patterns realized as abstract metrical templates necessarily involve two or more syllables, for which a contrast can be defined (Ladd, 2008; Liberman & Prince, 1977), and are not directly associated with any segmental properties. Special notation can be used to indicate the number of syllables and their relative prominence. For example, ['σ σ] can stand for a trochee, that is, a pair of syllables of which the first one is stressed. Under the abstract pattern approach, such templates are included in lexical representations (e.g., in the word form stratum of the

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[2] The term “subphonetic variability” may refer to any within-category differences in acoustic/phonetic features that are unrelated to phonetic identity (e.g., intensity) or to differences that are too small to signal a change in phonetic identity or in a direction away from a contrasting segment (e.g., voice onset time).

WEAVER++ speech production model; Levelt, Roelofs, & Meyer, 1999) and, if used in the course of perception, they must be derived from the (spoken or orthographic) input.

In contrast, mapping of graded prosodic properties need not involve entire metrical templates and therefore may also occur within single syllables. Conceivably, prosodic properties might be bound to the corresponding segmental specifications or might constitute standalone cues. That is, the lexical representation of a word such as “meter” may specify a [long loud i] in the first syllable or it may specify [long/loud] as a prosodic property independently from the /i/. In either case, the duration and intensity specification are graded prosodic properties involved in signaling phonetically what is theoretically taken to be a (metrical) phonological stress distinction.

Are stress-related prosodic properties directly involved in lexical activation and selection or are they used to build abstract metrical templates to match corresponding frames hypothesized to accompany lexical forms in the mental lexicon? To examine this question, studies must go beyond the phonetic matches of fragment priming and seek more direct evidence for the activation of abstract metrical templates. A number of studies have examined the potential processing facilitation that might be attributable to stress matching in the absence of segmental or lexical matching. Slowiaczek, Soltano, and Bernstein (2006) used auditory lexical decision and immediate repetition, in the context of stress matching and mismatching auditory primes, and failed to obtain any evidence for stress priming. These results are important but one might argue that they cannot be conclusively interpreted due to complications arising from the nature of the English language, in which stress is strongly associated with vowel quality. Specifically, because stress and segmental cues are typically confounded, English listeners may not rely on prosodic cues alone for stress pattern distinctions (Cooper et al., 2002; van Donselaar et al., 2005). This interpretation is supported by findings that stress minimal pairs, that is, segmentally identical words that are distinguished by stress (such as forbear "ancestor" vs. forbear "tolerate") can be effectively homophonous (perceptually) in English, producing the same patterns of associative priming (Cutler, 1986). In comparison, stress minimal pairs in Dutch (e.g., voornaam "first name" vs. voornaam "respectable") are not functional homophones and do not facilitate each other (no identity priming; Cutler & van Donselaar, 2001). Moreover, the materials of Slowiaczek et al. in the same-stress condition were not fully matched in metrical structure, potentially undermining the basis for a priming effect.

Studies have also been conducted in Italian. Colombo and Zevin (2009) provided evidence for stress priming in a reading aloud task. Participants were presented with word targets following sequences of five word or nonword primes with a consistent stress pattern. In Italian there is a dominant stress pattern, namely penultimate syllable stress, but there are also words stressed on the antepenult. Words of the latter type were misstressed, that is, incorrectly assigned the dominant stress pattern, when following nonword primes but not when following word primes. This result is consistent with a sublexical priming effect in word production. Similar results have been obtained from children using a primed nonword reading task, although the effects were smaller in the younger ages, reflecting the development of lexical neighborhoods (Colombo, Deguchi, & Boureux, 2014). Colombo and Zevin (2009) suggested that stress patterns can be sublexically activated and sustained as part of output representations, but not as a result of lexical phonological representations. However, Sulpizio, Job, & Burani (2012) found that words were read aloud faster when preceded by individual briefly presented (86 ms) stress-matched word primes, compared to stress-mismatched primes. Because stress was not sublexically predictable for these items, Sulpizio et al. concluded that the priming effect must have originated in lexical retrieval. However, the reading-aloud task format complicates any interpretation regarding the locus of the effect, because production is involved, as in the studies of Colombo and colleagues. Indeed, more recently, Sulpizio and Job (2015) obtained similar findings with masked (50 ms) primes sharing onset syllable, and attributed the effect to the phonological output buffer. Thus, due to the output (i.e., speech production) requirements, these studies with visually presented words have not produced unequivocal evidence for metrical representations that can be activated in the *perceptual* processing of words.

Production studies, on the other hand, have not consistently produced evidence for stress priming. In a picture naming task in Dutch, Schiller, Fikkert, and Levelt (2004) presented auditory primes matched or mismatched in stress to the target word (the pictured noun) at a variety of stimulus onset asynchrony (SOA) conditions (−200, 0, +150, +300 ms). They found that targets with initial stress were produced faster than targets with final stress. However, there was no stress priming effect, casting doubt on the proposal that stress patterns are stored in the lexicon. This stands in contrast to production models positing metrical information stored in the lexicon (when unpredictable) and activated in production separately from segmental representations (such as the WEAVER++ model; Levelt et al., 1999). However, as noted by Roelofs and Meyer (1998), metrical priming would emerge in this model only if metrical assembly were faster than segmental assembly. In fact metrical and segmental spell-out are posited to run in parallel, consistent with metrical priming observed only when initial segments overlap. That is, facilitation was observed when prime and target shared initial segments in addition to syllable structure and stress pattern.

Other studies examining stress effects in reading have produced mixed findings. On the one hand, stress is known to affect visual word recognition in lexical decision and naming tasks insofar as words that are atypically stressed, compared to their neighborhood, or misstressed, are processed more slowly or less accurately (in Italian; Burani & Arduino, 2004; Colombo, 1992). On the other hand, direct evidence for stress representations has been difficult to obtain in visual tasks. In Spanish, Gutiérrez-Palma and Palma-Reyes (2008) used a lexical decision task with masked primes that were the same as the target words, either correctly or incorrectly stressed, as indicated by a stress diacritic.[3] There was no difference between the correct stress condition (e.g., actór) and the control condition, in which the masked prime bore no stress diacritic (e.g., actor). Targets preceded by incorrectly stressed primes were responded to more slowly than in the control condition, but only at relatively long SOA, 100–143 ms. These results were interpreted as indicating that stress assignment is a late process in reading. Thus, the prime diacritic does not have a chance to affect the subsequent target within a brief time period (short SOA) because it takes longer to process. At longer SOA, a redundant cue will cause neither facilitation nor inhibition if it arrives after another process (lexical or sublexical) has already assigned stress appropriately. In contrast, a mismatching cue will cause a delay if it conflicts with the stress assignment process.

This interpretation has also been applied to Greek children's reading aloud words with missing or misplaced stress diacritics. Omission did not affect performance but misplaced diacritics resulted in a small delay (Protopapas & Gerakaki, 2009). No metrical representation is necessary in this interpretation because the stress match or mismatch may occur entirely within the orthographic representation of the word, which presumably includes the diacritic.

Besides lexical decision and reading aloud tasks, evidence that metrical

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[3] The Spanish orthography marks stress with a diacritic only in certain cases, which did not include the experimental targets (e.g., actor), therefore the diacritics on the masked primes of this study were either redundant (actór) or incorrect (áctor), and in both cases orthographically inappropriate.

information is part of word representation during silent reading has been provided by eye movement studies in English. Ashby and Clifton (2005) found that participants fixated more on words with two stressed syllables than on words with only one stressed syllable, concluding in favor of an “implicit prosody” hypothesis. They also suggested that stress assignment occurs late in the lexical access process. More recently, Breen and Clifton (2011, 2013) provided further support for implicit prosody during silent reading, documenting eye movement costs when prosodic expectations are violated. The processing cost of metrical reanalysis suggests that metrical representations of text, including lexical stress patterns, are computed during silent reading (cf. costs of metrical violations in speech: Domahs et al., 2014; Knaus et al., 2007; Rothermich et al., 2010; Schmidt-Kassow, & Kotz, 2009; Schmidt-Kassow et al., 2011). Notably, in these experiments, expectations were produced by explicit meter of poetry verses and by syntactic exploitation of noun-verb ambiguity, and were interpreted in terms of output processes involved in subvocalization (“inner speech”), consistent with the aforementioned interpretation of naming studies in other languages.

Overall, it seems clear that stress patterns are involved in lexical representations, at least for items with nondefault patterns, in output representations for speech production. The nature of these stress representations remains unclear because so far there are no priming effects specific to metrical structure. All observed effects have involved either lexical match or production, so they may be ascribed to lexical or output representations rather than to abstract metrical templates. Moreover, much research on stress has taken place in English, in which vowel quality dominates stress distinctions and precludes conclusions specific to prosodic features. Similarly, findings from auditory word recognition are difficult to interpret because stress patterns are necessarily confounded with the acoustic properties that signify them, so it is not clear whether the observed effects should be ascribed to metrical templates contrasting abstract syllables, as required by phonology, or to acoustic phonetic properties associated with particular word parts.

Therefore, to conclude that abstract stress representations are involved in word recognition, we need to investigate the potential of *visual* words to activate stress patterns that can be sustained beyond specific lexical items. This should be done in a language that does not confound prosodic with segmental properties. To ensure that stress patterns are represented as such, and are not an intrinsic part of lexical representations, we need to examine a language that puts no phonological constraints on stress position and marks stress orthographically, thereby allowing the use of unambiguously stressed pseudoword stimuli with stress patterns that can be freely manipulated, regardless of putative default patterns and typicality effects.

Greek combines all these desirable properties. It is a free-stress language in which every word with two or more syllables carries a single stress (Arvaniti, 2007). Stress falls on one of the last three syllables of the word (Malikouti-Drachman & Drachman, 1989). Beyond this constraint there are no known phonological restrictions as to which vowels or syllable types may carry stress, so stress is phonologically unpredictable (making Greek a language with a lexical accent system; Revithiadou, 1999). Stressed vowels stand out phonetically by being longer and louder than unstressed vowels (Arvaniti, 2000, 2007). Unstressed vowels exhibit only limited centralization (i.e., tendency to neutral articulation) and, crucially, there is no phonological vowel reduction associated with lack of stress (Arvaniti, 2007; Fourakis, Botinis, & Katsaiti, 1999). The Greek orthography is relatively transparent at the grapheme-phoneme level (estimated consistency 95% for reading and 80% for spelling; Protopapas & Vlahou, 2009). Stress is orthographically marked with an acute accent on the vowel of the stressed syllable in every word with two or more syllables. Therefore, there is a reliable visual stimulus associated with stress position in the orthography.[4] This diacritic is obligatory and it is taught at school as part of regular reading instruction starting in Grade 1. The contrastive role of stress is evident in stress minimal pairs and triplets, that is, segmentally identical words that differ only in stress and are disambiguated orthographically by the diacritic (e.g., μέτρο /<u>me</u>tro/ “meter” – μετρό /me<u>tro</u>/ “metro”). Finally, Greek has relatively few single-syllable content words (less than 2.5% of tokens; Protopapas & Vlahou, 2009). Therefore stress assignment concerns the vast majority of spoken and written content words in typical language use. A relative preponderance of penultimate stress words (about 28% of all word tokens, or 44% of multisyllables; Protopapas, 2006) offers only weak basis for a structural default (Protopapas & Gerakaki, 2009).

In the present study we set out to document the activation of stress patterns in a series of priming experiments, contrasting stress-congruent to stress-incongruent prime-target pairs. If prosody is implicitly activated when viewing individual words, then the stress pattern of the prime should support or interfere with that of the target. We used a lexical decision task for two reasons: First, to avoid the involvement of representations and processes specific to production (as might occur in naming tasks); and second, to avoid manipulations drawing explicit attention to potentially task-induced representations (as might occur in rhyming judgment tasks). In addition to the word prime-target pairs we included pseudoword prime-target pairs to allow sublexical

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[4] There are also probabilistic associations between stress patterns and letter sequences, specifically word beginnings and endings (Monaghan, Arciuli, & Seva, in press), partly related to morphological suffixes (Grimani & Protopapas, 2009); however these are demonstrably very weak and unlikely to contribute significantly to stress assignment when lexical or diacritic information is available.

match effects to be identified, in case stress patterns are computed sublexically. (To ensure attention to the target, filler items included word-pseudoword and pseudoword-word prime-target pairs.) Primes and targets shared their initial syllable, to delay lexical inhibition due to competition from mismatching onsets, and to allow metrical priming effects to emerge in case segmental and metrical processing takes place in parallel in perception (as in production; cf. Roelofs & Meyer, 1998). Primes and targets shared no more than their initial syllable, thus any priming obtained cannot be attributed to lexical matching.

In addition, to address the nature of lexical stress representations, we applied prime-target matching with both penultimate- and antepenultimate-syllable stress. This decision was based on the suggestion of Levelt et al. (1999) that the default stress pattern is not specified in the lexicon but computed by a nonlexical process. In Greek the status of the default pattern it is not entirely clear. Kappa (2002) and Malikouti-Drachman and Drachman (1989) consider the trochaic foot to be unmarked, in the linguistic sense, reflecting a universal tendency. Stress assignment data in pseudoword reading are consistent with a preference for penultimate syllable stress (but see discussion in Protopapas, 2006; Protopapas & Gerakaki, 2009). If penultimate-syllable stress is not marked in the lexicon, then stress priming should not occur with targets having this stress pattern, as there would be no lexical stress representation for an incoming pattern to match or mismatch. However, matching should be possible for targets stressed on the antepenultimate, which, by this account, must be fully specified. To ensure that any differences found between targets stressed on the penultimate and antepenultimate can be attributed to the stress pattern, items were matched on a variety of lexical and sublexical variables.

General Methods

Participants

Participants in the following experiments were adults (18–35 years old), primarily undergraduate and graduate students who volunteered or received course credit for participation. In every experiment, data from participants with more than 25% total errors on word targets or 30% in pseudoword targets were discarded.

Materials

Words and their properties were derived from the C corpus of the ILSP Psycholinguistic Resource (IPLR; speech.ilsp.gr/iplr; Protopapas, Tzakosta, Chalamandaris, & Tsiakoulis, 2012).

A starting set of 140 syllables were identified that appeared word-initially in 3-syllable words, subject to the following constraints: (a) The 3-syllable words beginning with each syllable were fewer than words with more or fewer syllables (ratio between 0.2 and 1); (b) the number of penultimate-stress and antepenultimate-stress 3-syllable words beginning with each syllable was relatively balanced (ratio between 0.5 and 2.0); and (c) their summed token frequencies were not too dissimilar (ratio between 0.3 and 3.0). This was meant to ensure that hearing these syllables would not induce strong expectations for a particular word length or stress pattern.

From this set, twenty word-initial syllables were subsequently selected, for which groups of six words could be identified, with the following properties: (a) All six words were three syllables long, began with the same syllable, and had the same number of letters and the same C/V (consonant-vowel) syllabic structure; (b) three of the words were stressed on the penultimate syllable and three on the antepenultimate; and (c) the words were all morphologically unrelated. Within each group of six words, the three penultimate-stress words and the three antepenultimate-stress words were matched as closely as possible on frequency, mean log bigram frequency, number of phonological and orthographic neighbors, number of higher-frequency orthographic neighbors, and phonological cohort size. The final selection of the entire group of 120 words was made aiming to minimize group differences in the aforementioned properties between penultimate-stress and antepenultimate-stress words (Table 1).

Subsequently, matched pseudoword groups were constructed, based on the word groups, mainly by switching syllables around, occasionally exchanging an additional phoneme to achieve a better match or to avoid a lexical item. There were, thus, 20 groups of six pseudowords each, with the same initial syllable, length, CV structure, etc., as the 20 word groups. An example word-pseudoword set is shown in Table 2, along with the associated properties.

Each word group was then used to form six combinations of prime-target pairs. In each combination, one penultimate-stress word and one antepenultimate-stress word were the designated targets, whereas the other two of each were the designated primes. Each target was paired with one matching-stress prime and one mismatching-stress prime, for a total of four prime-target pairs. Therefore each of the two primes occurred once in each combination and each of the two targets occurred twice, for a within-participant and within-item contrast of stress match. Six different target pairs from each group were used to form six experimental lists. Each list included 80 word trials (20 word groups × 4 prime-target pairs per group). The pseudoword groups were processed in exactly the same way, leading to an additional 80 pseudoword trials to each experimental list. Table 3 illustrates the assignment scheme to prime and target conditions over the six experimental lists.

In addition to the 160 experimental trials, a common set of 160 filler trials were added to each experimental list. Half of these had word targets and half pseudowords;

with counterbalanced word and pseudoword primes of matching and mismatching stress. Each filler prime-target pair was also matched in initial syllable, length and syllable structure. The items were selected from among the rejected initial syllable sets. The purpose of the cross-lexical filler pairs (i.e., word primes with pseudoword targets and vice versa) was to ensure that participants would not respond on the basis of the lexicality of the prime but would have to attend to the target.

Finally, each experimental list began with 14 practice trials of the same structure, common to all lists, with mixed word and pseudoword prime-target pairings, to familiarize participants with the task and to instill the need to attend to the target.

Procedure

Primes were presented unmasked, followed by the targets (see individual experiments for timing and form details). Stimulus presentation and response collection was controlled by DMDX (Forster & Forster, 2003). Auditory stimuli (primes and/or targets) were presented binaurally through stereo headphones. Participants performed a lexical decision task on the target, pressing one key on the computer keyboard for "word" and another for "pseudoword." They were instructed to pay attention to both prime and target stimuli. The order of trials was randomized for each participant.

Data Analysis

Response times, for correct responses only, were logarithmically transformed and analyzed with general linear mixed-effects models with crossed random effects for participants and items (Baayen, 2008; Baayen et al., 2008) using function lmer of the lme4 package (Bates, Maechler, Bolker, & Walker, 2014) in R 3.0.2 (R Core Team, 2013). Although maximal random structures were desirable (Barr et al., 2013), they were precluded by convergence problems, therefore random slopes were included only for the critical variable, namely stress congruence between prime and target. The model formula, in R notation, was congr*strpos+(congr|subject)+(congr|item), including fixed effects of stress congruence (congr: matching vs. mismatching) and stress position (strpos: penultimate vs. antepenultimate), using deviation contrasts (via contr.sum) to produce estimates of main effects. For significance testing, *p* values were calculated with Satterthwaite's approximation for the fixed effects and with log-likelihood ratio tests for the random effects, using package lmerTest (Kuznetsova, Brockhoff, & Christensen, 2014). Accuracy was analyzed with generalized mixed-effects models for binomial distributions (Dixon, 2008) via a logit transformation (Jaeger, 2008), using the same model formula in function glmer of the lme4 package.

As there are 12 tests in each experiment (main effects of congruence and stress position plus their interaction, in accuracy and response time, for words and pseudowords: 3×2×2=12), a Bonferroni experiment-wise adjustment of alpha to .05 would require *p* values of individual effects not to exceed .0041 to be considered statistically significant; a more stringent study-wise adjustment taking into account that these analyses were performed for six experiments would bring the significance threshold to .00069, a value too low by psycholinguistic standards, risking greatly elevated Type II error rates. In the following analyses a significance threshold α = .005 was applied; effects with *p* values between .05 and .005 are considered "marginally significant."

Experiment 1a

In the first experiment we tested whether visual primes can facilitate the processing of auditory targets when matched in stress pattern, compared to primes mismatched in stress. Although written words in Greek carry a stress diacritic, clearly and unambiguously indicating the presence of the stressed syllable, this does not necessarily mean that a metrical representation is activated. It is possible that the diacritic might only serve to identify the orthographic representation of the word, or that it is not even taken into account at all (indeed, there are data consistent with the hypothesis that the diacritic is underused; see discussion in Protopapas & Gerakaki, 2009). In contrast, incoming spoken words necessarily carry acoustic information that constitutes the phonetic realization of the stress contrast and therefore is directly relevant to the stress pattern: one syllable is bound to be louder, longer, and possibly spoken with a distinguishing pitch contour (Arvaniti, 2007). This information would not only be difficult to ignore, but it might also connect more directly with output representations underlying production of the same word, at the phonetic level rather than an abstract metrical phonological tier. In other words, potential stress priming effects based on intramodal auditory tasks may not necessarily indicate the presence and activation of stress representations. Therefore, to facilitate interpretation, we selected to present visual primes and auditory targets. If stress priming occurs, then an amodal, abstract metrical representation could be more clearly implicated.

Stress priming effects obtained with word stimuli would not allow us to conclude whether the shared representations underlying facilitation were derived lexically or sublexically, because once words are accessed in the lexicon their stress patterns would be immediately available as well, potentially contributing to the priming effect. Therefore, we included pseudoword prime-target pairs to examine the potential formation of stress representations by sublexical processes. Finally, because stress assignment has been claimed to constitute a late-occurring stage in visual word recognition (cf. Ashby & Clifton, 2005; Gutiérrez-Palma & Palma-Reyes, 2008), a relatively long SOA was used, to allow sufficient time for stress patterns to be activated and become available for facilitation or interference.

Method

Participants

Data were collected from 72 participants. Four were removed due to slowness (mean response time > 1500 ms, more than 2.5 SD from the from the mean of all participants in all experiments), leaving data from 68 participants for further analysis.

Materials

The experimental target list (120 words and 120 pseudowords) and the filler target list (80 words and 80 pseudowords) were recorded by a male native speaker of Greek (the first author) and stored in individual audio files. The mean duration of the target stimuli was 612 ms (*SD* = 66 ms) for penultimate-stress words, 573 ms (*SD* = 62 ms) for antepenultimate-stress words, 602 ms (*SD* = 54 ms) for penultimate-stress pseudowords, and 566 ms (*SD* = 63 ms) for antepenultimate-stress pseudowords. In 2 × 2 ANOVA of stimulus duration, with lexicality and stress position as fixed factors, there was no significant difference between words and pseudowords ($F(1, 236) = 1.11$, $p = .293$, $\eta_G^2 = .004$) and no interaction. Penultimate-stress stimuli were significantly longer than antepenultimate-stress stimuli ($F(1, 236) = 23.26$, $p < .001$, $\eta_G^2 = .090$). Table 4 lists the duration, pitch, and intensity of each syllable for words and pseudowords, as measured using Praat (Boersma & Weenink, 2007).

Procedure

Each trial began with a fixation cross, presented at the center of the screen for 250 ms, followed by a 250-ms blank screen. The prime was then presented at the center of the screen in 20-pt black Arial font on a white screen for 250 ms and was then replaced on the screen by a mask composed of six number signs (#), presented for 250 ms. The auditory target commenced simultaneously with the mask onset. Thus the intended prime-target stimulus onset asynchrony (SOA) was 250 ms.[5] Lexical decision keypress responses were collected beginning at the onset of the audio file, with a 5-s timeout period. The next trial followed after 1500 ms. The entire session lasted about 20 minutes, with a brief break provided halfway through the experiment.

Results

There were no timed out trials. The total overall proportion of incorrect experimental trials (including both words and pseudowords but not fillers) was 6.0%.

For words, Figures 1 and 2 show the distributions of accuracy (proportion of incorrect responses) and the logarithmic mean of response time per participant in each condition. There was no effect of stress congruence ($\beta = -0.026$, $z = -0.324$, $p = .746$) or stress position ($\beta = 0.020$, $z = 0.133$, $p = .894$) on accuracy, and no interaction between the two factors ($\beta = -0.016$, $z = -0.313$, $p = .755$). Similarly, there was no effect of stress congruence ($\beta = -0.003$, $t = -1.148$, $p = .251$) or stress position ($\beta = -0.001$, $t = -0.129$, $p = .897$) on response time, and no interaction ($\beta = -0.002$, $t = -0.712$, $p = .477$).

To alleviate concerns due to the repeated presentation of the same target, we reanalyzed the data including only the first presentation of each target. There was no effect of stress congruence ($\beta = 0.077$, $z = 0.608$, $p = .543$) or stress position ($\beta = 0.081$, $z = 0.507$, $p = .612$) on accuracy, and no interaction between the two factors ($\beta = -0.011$, $z = -0.140$, $p = .888$). Similarly, there was no effect of stress congruence ($\beta = -0.001$, $t = -0.338$, $p = .736$) or stress position ($\beta = -0.003$, $t = -0.392$, $p = .695$) on response time,

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[5] Due to experimenter error, initial silent intervals remained in the files, so the auditory targets did not begin immediately at the audio file onset but after a variable delay (M = 100 ms, SD = 44 ms; range 5–238 ms). There was no significant difference in this delay between words and pseudowords or between penultimate- and antepenultimate-stress items (in 2×2 ANOVA, lexicality: $F(1, 236) = 0.88$, $p = .349$, $\eta_G^2 = .004$; stress position: $F(1, 236) = 3.02$, $p = .084$, $\eta_G^2 = .012$; interaction: $F(1, 236) = 0.08$, $p = .777$, $\eta_G^2 < .001$). Because of this delay, the *effective* SOA was 350 ms on average in Experiment 1a and 100 ms in Experiment 1b.

and no interaction ($\beta = -0.004$, $t = -1.151$, $p = .250$).

For pseudowords, Figures 3 and 4 show the distributions of participant performance. There was no effect of stress congruence ($\beta = -0.015$, $z = -0.091$, $p = .928$) or stress position ($\beta = 0.189$, $z = 1.542$, $p = .123$) on accuracy, and no interaction ($\beta = 0.083$, $z = 1.043$, $p = .297$). There was also no effect of stress congruence ($|\beta| < 0.001$, $t = 0.175$, $p = .862$) or stress position ($\beta = 0.008$, $t = 1.388$, $p = .168$) on response time, and no interaction ($\beta = 0.003$, $t = 1.386$, $p = .169$).

Discussion

There was no evidence for stress priming in this experiment, in either accuracy or latency, for either words or pseudowords. This may indicate that abstract stress patterns were not activated or were unavailable outside the lexical entries to which they belonged. However, it may be that, because of the long SOA, lexical activation of the prime had enough time to inhibit competitors, including words with the same first syllable. Thus an effect of the stress pattern may have been counteracted by inhibition of the target prior to its occurrence. To test for this possibility we repeated the experiment with a short SOA, which would not allow enough time for lexical activation to inhibit competitors.

Experiment 1b

This experiment was identical to Experiment 1a except for the SOA. Instead of being separated by 250 ms, visual primes and auditory targets were now presented simultaneously.

Method

Participants

Data were collected from 62 participants. One was removed due to inaccuracy (more than 25% errors on word targets), leaving data from 61 participants for further analysis.

Materials

The materials were identical to those in Experiment 1a.

Procedure

The procedure was identical to that of Experiment 1a with the only exception that there was no delay (0 ms) between the visual presentation of the prime and the auditory presentation of the target (resulting in an effective SOA of approximately 100 ms, as explained in Footnote 5). The visual mask replaced the prime on screen simultaneously with the offset of the auditory target.

Results

There were no timed out trials. The proportion of incorrect trials was 5.8%.

The distributions of participant performance are shown in Figures 1–4. There was no effect of stress congruence ($\beta = 0.071$, $z = 0.868$, $p = .385$) or stress position ($\beta = -0.091$, $z = -0.610$, $p = .542$) on accuracy, and no interaction between the two factors ($\beta = -0.037$, $z = -0.689$, $p = .491$). Similarly, there was no effect of stress congruence ($\beta = 0.003$, $t = 1.247$, $p = .217$) or stress position ($\beta = -0.005$, $t = -0.733$, $p = .465$) on response time, and no interaction ($\beta = 0.002$, $t = 0.714$, $p = .475$).

In reanalysis including only the first presentation of each target, there was no effect of stress congruence ($\beta = 0.257$, $z = 1.756$, $p = .079$) or stress position ($\beta = -0.073$, $z = -0.416$, $p = .678$) on accuracy, and no interaction between the two factors ($\beta = -0.153$, $z = -1.799$, $p = .072$). Similarly, there was no effect of stress congruence ($\beta = -0.001$, $t = -0.345$, $p = .731$) or stress position ($\beta = -0.003$, $t = -0.307$, $p = .760$) on response time, and no interaction ($\beta = 0.001$, $t = 0.323$, $p = .746$).

For pseudowords, Figures 3 and 4 show the distributions of participant performance. There was no effect of stress congruence ($\beta = 0.439$, $z = 1.795$, $p = .073$) or stress position (β = −0.063, z = −0.386, p = .700) on accuracy, and no interaction (β = −0.047, z = −0.426, p = .670). There was also no effect of stress congruence ($|\beta|$ < 0.001, t = −0.105, p = .916) or stress position (β = 0.008, t = 1.482, p = .141) on response time, and no interaction (β = 0.001, t = −0.386, p = .699).

Discussion

There was no evidence for stress priming in this experiment, consistent with Experiment 1a, indicating that abstract stress representations were not involved in performing the lexical decision task. One might argue that a short SOA on the one hand prevents the buildup of lexical competition but on the other hand leaves insufficient time for stress representations to be activated (given that stress assignment occurs late in visual word recognition; Ashby & Clifton, 2005; Gutiérrez-Palma & Palma-Reyes, 2008). If lexical inhibition is strong before the completion of the metrical assembly then stress priming will never be observed. To address this possibility, Experiment 2 employed auditory primes. In spoken word recognition stress information constrains lexical access rapidly (as soon as a stressed syllable occurs; Reinisch et al., 2009; Sulpizio & McQueen, 2012). Therefore, auditory primes ought to activate their stress patterns immediately. If visual targets appear at prime offset, the stress pattern of the prime, if abstractly represented, will be available to facilitate the activation of the visual target, causing cross-modal stress priming. This possibility was tested in Experiment 2.

Experiment 2

Experiment 2 was identical to Experiments 1a/1b except that modalities were reversed: Primes (the same items) were presented auditorily and targets were presented visually.

Method

Participants

Data were collected from 63 participants. Three were removed due to inaccuracy (more than 25% errors on word targets or 30% on pseudoword targets), leaving data from 60 participants for further analysis.

Materials

The materials were identical to those in Experiment 1, except that the modality of presentation was switched: the auditory (recorded) version was used for the primes and the visual (printed) version for the targets. For the primes, stimuli from Experiments 1a/1b were trimmed to align stimulus onset and offset with the beginning and end of the audio file.

Procedure

Each trial began with a fixation cross, presented at the center of the screen for 500 ms, followed by a 250-ms blank screen. The prime was then presented auditorily. At the prime offset, the visual target was presented immediately at the center of the screen in 20-pt black Arial font on a white screen for 500 ms. Thus the SOA was equal to the duration of the auditory prime (see Materials in Experiment 1a). Response collection timed out 2000 ms after the appearance of the target.

Results

There were 33 timed out trials (0.3%). The proportion of incorrect experimental trials was 7.1%.

The distributions of participant performance are shown in Figures 1–4. In accuracy, there was no effect of stress congruence ($\beta = 0.068$, $z = 0.872$, $p = .383$) or interaction between the two factors ($\beta = 0.057$, $z = 1.055$, $p = .292$), but there was a marginally significant effect of stress position ($\beta = -0.237$, $z = -1.979$, $p = .048$, indicating more accurate responses to penultimate-stress targets). Similarly, in response times there was no effect of stress congruence ($\beta = 0.003$, $t = 0.950$, $p = .344$) or interaction ($|\beta| < 0.001$, $t = -0.172$, $p = .863$), but there was a marginally significant effect of stress position ($\beta = -0.019$, $t = -2.492$, $p = .014$; faster responses to penultimate-stress targets).

In reanalysis including only the first presentation of each target, there was no effect of stress congruence ($\beta = 0.093$, $z = 0.765$, $p = .444$) or stress position ($\beta = -0.220$, $z = -1.559$, $p = .119$) on accuracy, and no interaction between the two factors ($\beta = 0.036$, $z = 0.479$, $p = .632$). In response times there was no effect of stress congruence ($\beta = 0.002$, $t = 0.465$, $p = .643$) or interaction ($\beta = 0.001$, $t = 0.210$, $p = .834$), but there was again a marginally significant effect of stress position ($\beta = -0.020$, $t = -2.148$, $p = .034$).

For pseudowords, Figures 3 and 4 show the distributions of participant performance. In accuracy, there was a marginally significant effect of stress congruence ($\beta = 0.290$, $z = 2.454$, $p = .014$), no effect of stress position ($\beta = 0.195$, $z = 1.498$, $p = .134$), and no interaction ($\beta = -0.122$, $z = -1.704$, $p = .088$). In response times, there was no effect of stress congruence ($\beta = -0.002$, $t = -0.760$, $p = .449$) or stress position ($\beta = 0.016$, $t = 1.899$, $p = .060$), and no interaction ($\beta = -0.004$, $t = -1.516$, $p = .132$).

Discussion

There was no evidence for stress priming in this experiment. The marginally significant difference in pseudoword accuracy is not only above the adjusted significance threshold, but also in the opposite direction, consistent with slightly increased error proportion in the congruent, compared to the incongruent condition. Taken together with the results of Experiments 1a-1b, the lack of cross-modal stress priming effects suggests that no amodal metrical templates are activated perceptually across lexical items and across modalities. This does not rule out intramodal stress congruence effects, which would be consistent with a meter-sensitive mechanism accounting for the “implicit prosody” findings in silent reading experiments (Ashby & Clifton, 2005; Breen & Clifton, 2011, 2013). To examine this possibility, in Experiment 3 we used visual primes and visual targets.

Experiment 3

This experiment employed the same materials as before but now both targets and primes were in the visual modality. Although Experiments 1a and 1b produced no evidence for cross-modal stress priming, it is possible that reading involves meter processing mechanisms that include abstract metrical frames shared across words with the same stress pattern. If so, then these frames should be subject to priming.

Method

Participants

Data were collected from 65 participants. Five were removed due to inaccuracy (more than 25% errors on word targets or 30% on pseudoword targets), leaving data from 60 participants for further analysis.

Materials

Visual primes were as in Experiments 1a/1b and visual targets as in Experiment 2.

Procedure

Each trial began with a mask composed of ten number signs (#), presented in 20-pt black Arial font at the center of the white screen for 500 ms. The prime was then presented visually for 133.3 ms, in 15-pt black Arial font, replacing the mask at the center of the screen without delay. At the prime offset, the visual target was presented immediately at the center of the screen in 20-pt black Arial font until a response was registered. Thus the SOA was 133.3 ms, to match the condition producing a priming effect in Gutiérrez-Palma and Palma-Reyes (2008). Response collection timed out 2000 ms after the appearance of the target. The next trial followed after 1000 ms.

Results

There were 75 timed out trials (0.8%). The proportion of incorrect trials was 7.9%.

The distributions of participant performance are shown in Figures 1–4. In accuracy, there was no effect of stress congruence ($\beta = -0.112$, $z = -1.564$, $p = .118$) or interaction between the two factors ($\beta = 0.012$, $z = 0.235$, $p = .814$), but there was a significant effect of stress position ($\beta = -0.321$, $z = -2.821$, $p = .005$, indicating more accurate responses to penultimate-stress targets). Similarly, in response times there was no effect of stress congruence ($|\beta| < 0.001$, $t = -0.040$, $p = .968$) or interaction ($\beta = 0.006$, $t = -1.613$, $p = .107$), but there was a significant effect of stress position ($\beta = -0.040$, $t = -5.677$, $p < .001$, indicating faster responses to penultimate-stress targets).

Similarly, in reanalysis including only the first presentation of each target, for accuracy there was no effect of stress congruence ($\beta = -0.171$, $z = -1.598$, $p = .110$) or interaction ($\beta = 0.007$, $z = 0.092$, $p = .927$), but there was a marginally significant effect of stress position ($\beta = -0.306$, $z = -2.445$, $p = .015$). In response times there was no effect of stress congruence ($\beta = -0.003$, $t = -0.563$, $p = .575$) or interaction ($\beta = 0.005$, $t = 0.945$, $p = .345$), but there was again a significant effect of stress position ($\beta = -0.042$, $t = -4.667$, $p < .001$).

For pseudowords, Figures 3 and 4 show the distributions of participant performance. In accuracy, there was no significant effect of stress congruence ($\beta = -0.124$, $z = -1.111$, $p = .267$) or stress position ($\beta = 0.162$, $z = 1.204$, $p = .229$), and no interaction ($\beta = -0.061$, $z = -0.908$, $p = .364$). In response times, there was no effect of stress congruence ($\beta = -0.003$, $t = -0.971$, $p = .333$) or interaction ($\beta = 0.001$, $t = 0.239$, p

= .812), but there was a marginally significant effect of stress position ($\beta = 0.017$, t = 6.234, p = .028, indicating faster responses to antepenultimate-stress targets).

Discussion

There was no evidence for stress priming in this experiment. There was an effect of stress position, such that words with penultimate-syllable stress were responded to faster than words with antepenultimate-syllable stress, but stress congruence among primes and targets did not affect either the accuracy or the latency of the responses. This result bolsters the conclusion that abstract metrical frames are not involved in visual word recognition. Therefore any prosodic effects observed in reading should be attributed directly to output lexical processing or indirectly to lexically-mediated representations that cannot be detached from the specific lexical items.

One possibility remains to be investigated, concerning the auditory modality. If stress patterns are activated by incoming spoken words, and if these patterns are sufficiently abstract, then intramodal stress priming will be observed with auditory stimuli. Although Slowiaczek et al. (2006) observed no such effect in English, the fact that stress in Greek is not confounded with vowel quality should allow priming effects to emerge provided a large and well controlled stimulus set is employed.

Experiment 4

In this experiment the same materials as in the previous experiments were presented auditorily, to test whether stress priming occurs with spoken primes and spoken targets.

Method

Participants

Data were collected from 79 participants. Five were removed due to inaccuracy (more than 25% errors on word targets or 30% on pseudoword targets), leaving data from 74 participants for further analysis.

Materials

Auditory primes were as in Experiment 2.

Procedure

Each trial began with a fixation cross, presented at the center of the screen for 250 ms, followed by a 250-ms blank screen. A sequence of five dashes (-----) was then presented at the center of the screen, concurrent with auditory presentation of the prime. At the prime offset, the screen was cleared for 100 ms. Subsequently, a number sign (#) was presented concurrent with auditory presentation of the target. Thus the SOA was 100 ms longer than the duration of the auditory prime (see Materials in Experiment 1a). Response collection timed out 2000 ms after the appearance of the target. The next trial followed after 1000 ms.

Results

There were 82 timed out trials (0.7%). The proportion of incorrect trials was 8.0%.

The distributions of participant performance are shown in Figures 1–4. In accuracy, there was a marginally significant effect of stress congruence ($\beta = -0.142$, $z = -2.349$, $p = .019$); there was no effect of stress position ($\beta = -0.012$, $z = -0.081$, $p = .935$) and no interaction between the two factors ($\beta = -0.025$, $z = -0.571$, $p = .568$). In response times there was no effect of stress congruence ($\beta = -0.001$, $t = -0.467$, $p = .641$) or stress position ($\beta = -0.001$, $t = -0.195$, $p = .846$) and no interaction ($\beta = 0.002$, $t = -0.920$, $p = .360$).

In reanalysis including only the first presentation of each target, for accuracy there was no effect of stress congruence ($\beta = -0.056$, $z = -0.723$, $p = .469$) or stress position ($\beta = -0.016$, $\text{z} = -0.110$, $p = .913$) and no interaction ($\beta = 0.040$, $\text{z} = 0.702$, $p =$

.483). In response times there was no effect of stress congruence ($|\beta| < 0.001$, $t = 0.038$, $p = .970$) or stress position ($\beta = -0.001$, $t = -0.174$, $p = .862$). There was a marginally significant interaction ($\beta = -0.008$, $t = -2.227$, $p = .028$) but none of the simple effects were significant (broken down by either congruence or stress position).

For pseudowords, Figures 3 and 4 show the distributions of participant performance. In accuracy, there was no significant effect of stress congruence ($\beta = -0.087$, $z = -0.609$, $p = .542$) or stress position ($\beta = 0.019$, $z = 0.145$, $p = .885$). There was a marginally significant interaction ($\beta = -0.180$, $z = -2.371$, $p = .018$) but none of the simple effects were significant (broken down by either congruence or stress position). In response times, there was no effect of stress congruence ($\beta = 0.001$, $t = 0.420$, $p = .675$) or interaction ($\beta = -0.004$, $t = -1.877$, $p = .061$), but there was a significant effect of stress position ($\beta = 0.016$, $t = 2.959$, $p = .004$, indicating faster responses to antepenultimate-stress targets).

Discussion

There was no clear evidence for stress priming in this experiment. The marginally significant effect obtained for accuracy in words did not survive correction for second presentation of the target.

Pausing to take stock of the full range of Experiments 1–4, one may wonder whether stress priming effects may be too weak to be detected by our experiments. This appears unlikely due to the rather large number of participants and items in each experiment: There were 60 or more participants in each experiment and a total of 120 words and 120 pseudowords (60 each for each stress pattern), with each participant providing 80 data points in each lexicality condition. Materials were carefully selected and balanced. If priming effects cannot be detected under these conditions then they cannot be very important.

Still, if power were the major impediment to the discovery of stress priming, we should be able to improve our chances of obtaining a significant result by pooling the results from all four experiments together. To this effect, a four-factor mixed-effects analysis was undertaken, including the two factors in the analyses reported above (congruence and stress position) as well as two additional factors (target modality: auditory for Experiments 1a/1b and 4, and visual for Experiments 2 and 3; and prime modality: auditory for Experiments 2 and 4; and visual for Experiments 1a/1b and 3). All factors were allowed to interact. To avoid conservative tests, no random slopes were included in the model. With a total of 323 participants, model fitting for response times converged and produced a nonsignificant main effect of stress congruence ($\beta = 0.001$, $t = 0.561$, $p = .575$) and no significant interaction of stress congruence with any other factor. The magnitude of this effect ($\beta = 1.053\times10^{-3}$, $SE = 1.876\times10^{-3}$) over the intercept reference (6.715) corresponds to a difference of less than 1 ms, within a two-standard-error confidence interval of about ±3 ms. Under the modest expectation of a stress priming effect of 20 ms, these statistics result in a Bayes factor less than 0.1,[6] interpretable as strong evidence in favor of the null hypothesis (Dienes, 2014). Thus we can be reasonably confident in the lack of stress priming in our experimental paradigm.

Before reaching any final conclusions, in order to rule out the possibility that some oversight invalidated the experiments, causing the null results, it is important to show that the same materials produce priming effects if the effects do not depend on abstract metrical templates. This was the goal of the final experiment.

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[6] The "predicted" effect was assumed to be uniformly distributed between 0 and 0.047, the upper bound corresponding to about 40 ms over the 825-ms intercept (the natural exponential of 6.715). Calculated using the online Bayes factor calculator at http://www.lifesci.sussex.ac.uk/home/Zoltan_Dienes/inference/bayes_factor.swf

Experiment 5

Although evidence for stress priming based on abstract metrical matching has not been forthcoming, our materials should still produce priming effects that are lexically mediated, as in fragment priming. Referring to Table 2, it may be the case that the visual target φυλάμε (pronounced/filame/, with penultimate-syllable stress) is not recognized faster after hearing /fiðaci/ (φιδάκι, with penultimate-syllable stress) than after hearing /fiγate/ (φύγατε, with antepenultimate-syllable stress). But we expect that the same visual target should be recognized faster after hearing the first two syllables /fila/ with the same stress pattern (i.e., /fila/, matching segmentally and metrically the first two syllables of the target) than with a different stress pattern (i.e., /fila/, matching segmentally but mismatching metrically), taken from another word in the set (in this case, φίλαγε /filaʝe/).

Because the stimulus set was not designed with fragment priming in mind, there were two issues to solve: First, additional recordings were made, as needed, to obtain missing disyllables (with contrasting stress). Second, in many cases the first two syllables of a word also formed a word. In the above example, both /fila/ and /fila/ are words (inflected forms of the verb “to kiss” or “to guard”, differing in spelling). To avoid inhibiting the target, due to activation of the word fully matching the two-syllable fragment, we replaced the third syllable of the source items with noise, resulting in primes /fila**/ and /fila**/ (the asterisks denoting noise). Because the noise could be perceived as having masked an existing final syllable (cf. the phoneme restoration paradigm; Samuel, 1981), this manipulation was intended to allow the activation of matching words to proceed uninhibited.

Other than replacing the auditory primes with corresponding (stress congruent and incongruent) fragments, the experiment was the same as Experiment 2, with one exception: Because there was only one fragment in each stress congruence condition (rather than two matching and two mismatching word primes), there were now only three distinct experimental lists instead of six. The total number of participants, however, was matched to that of the previous experiments, by having more participants respond to each list, to maximize comparability of effect sizes.

Method

Participants

Data were collected from 77 participants. Sixteen were removed due to inaccuracy (more than 25% errors on word targets or 30% on pseudoword targets), leaving data from 61 participants for further analysis.

Materials

Visual targets were as in Experiments 2 and 3. Auditory primes were based on those of Experiments 2 and 4. For each target, including every word and pseudoword, there were two primes, both matching the target segmentally in the first two syllables, one of which also matched in stress while the other did not. The stress-matching prime was based on the target itself. The stress-mismatching prime was based on any item in the twelve-item set (six words and six pseudowords) with the appropriate constitution, that is, same segments but different stress pattern. In case no such item existed in the set, new prime items were recorded by the same speaker, who pronounced the target with correct and with incorrect stress. The waveforms of the two prime items were edited using praat (Boersma & Weenink, 2007) and manually marked at the end of the second syllable. Care was taken to exclude coarticulated cues to the following consonant (the third syllable onset) as much as possible, even if this meant placing the mark somewhat earlier than the full extent of the second vowel. The duration of the stimulus from this two-syllable mark through the end was then replaced by noise at a constant intensity matching that of the highest-intensity stressed vowels in the recording set (approximately 83 dB in the file). The noise was deemphasized white noise, approximating an average speech spectrum with a spectral tilt of −6 dB/octave. These noise-augmented fragments replaced the corresponding primes (with the same stress pattern) in the Experiment 2 lists. Because there was only one prime with each stress pattern, this resulted in three unique experimental lists, rather than six. Table 5 lists the duration, pitch, and intensity of each syllable, for fragments priming words and pseudowords.

Procedure

Each trial began with a fixation cross, presented at the center of the screen for 250 ms, followed by a 250-ms blank screen. A sequence of five dashes (-----) was then presented at the center of the screen, concurrent with auditory presentation of the prime. At the prime offset, that is, immediately after the noise, the visual target was presented at the center of the screen in 20-pt black Arial font on a white screen for 500 ms, followed by a blank screen. Thus the SOA was equal to the duration of the auditory prime (see Materials in Experiment 1a). Response collection timed out 2000 ms after the appearance of the target. The next trial followed after 500 ms.

Results

There were 50 timed out trials (0.5%). The proportion of incorrect trials was 9.9%.

The distributions of participant performance are shown in Figures 1–4. In accuracy, there were significant main effects of stress congruence ($\beta = -0.252$, $z = -3.732$, $p < .001$, indicating more accurate responses to stress-congruent targets) and stress position ($\beta = -0.341$, $z = -3.377$, $p = .001$, indicating more accurate responses to penultimate-stressed words) and no interaction between the two ($\beta = -0.010$, $z =$

−0.200, *p* = .842). In response times there were also significant main effects of stress congruence (*β* = −0.041, *t* = −11.581, *p* < .001, indicating faster responses to sress-congruent targets) and stress position (*β* = −0.037, *t* = −5.258, *p* < .001, indicating faster responses to penultimate-stressed words) and no interaction (*β* = 0.001, *t* = 0.310, *p* = .757).

In reanalysis including only the first presentation of each target, for accuracy there were significant effect of stress congruence (*β* = −0.300, *z* = −2.942, *p* = .003) and stress position (*β* = −0.380, *z* = −3.271, *p* = .001) and no interaction (*β* = −0.025, *z* = −0.332, *p* = .740). In response times there were significant effects of stress congruence (*β* = −0.039, *t* = −8.325, *p* < .001) and stress position (*β* = −0.040, *t* = −4.712, *p* < .001) and no interaction (*β* = 0.003, *t* = 0.722, *p* = .471).

To alleviate any concerns that the significant priming might be attributable to segmental, rather than stress, matching, owing to residual coarticulatory cues in the edited fragments, we reanalyzed the response time data including only targets with prime pairs based on recordings that were segmentally identical to each other through all three syllables (20.8% of the data). The results were the same; specifically, there were significant main effects of stress congruence (*β* = −0.031, *t* = −4.103, *p* < .001) and stress position (*β* = −0.055, *t* = −2.824, *p* = .011) and no interaction between the two (*β* = −0.010, *t* = −1.374, *p* = .170). Moreover, the priming effect did not differ significantly between targets with segmentally fully matched prime pairs and targets with prime pairs mismatched at the onset of the third (excised) syllable, as in analysis of all the data together, with segmental prime identity as an additional factor, there was no interaction of this factor with stress congruence (*β* = −0.024, *t* = −1.370, *p* = .173) and no triple interaction (*β* = 0.025, *t* = 1.388, *p* = .168).

For pseudowords, Figures 3 and 4 show the distributions of participant performance. In accuracy, there was no significant effect of stress congruence (β = 0.074, z = 1.003, p = .316). There was a marginally significant main effect of stress position (β = 0.251, z = 2.521, p = .012, consistent with more accurate responses to antepenultimate-stress items) and a marginally significant interaction (β = −0.132, z = −2.562, p = .010) owing to the effect of stress position being significant for incongruent targets only (β = 0.377, z = 2.996, p = .003). In response times, there was a marginally significant effect of stress congruence (β = −0.007, t = −2.446, p = .015), a significant effect of stress position (β = 0.025, t = 3.281, p = .001, consistent with faster responses to antepenultimate-stress items), and no interaction (β = −0.001, t = −0.195, p = .845).

Discussion

There was clear and unequivocal evidence for "stress" priming in this experiment, in agreement with previous findings in other languages (Cooper et al., 2002; Soto-Faraco et al., 2001; Tagliapietra & Tabossi, 2005; van Donselaar et al., 2005). Although the materials were not designed for this type of experiment, and were not fully controlled in ways that might be relevant for arguments based on fragment priming, these findings demonstrate that our materials did not preclude stress priming due to some inadvertent issue in design or implementation. In conjunction with the preceding experiments, we may conclude that fragment priming is lexically mediated, based on acoustic-phonetic matching between fragment and target, rather than some effect of abstract metrical representations matching or mismatching the target.

To alleviate concerns regarding our adjustment of the significance threshold, Figure 5 shows the estimated coefficients for the stress congruence effects over all experiments. Coefficients for words are plotted against those for pseudowords, along with error bars equal to two standard errors, for convenient comparisons. Clearly, β values for all accuracy tests and for all response time tests except for Experiment 5 hover around zero in a rather uniform cluster, with confidence intervals straddling zero in most cases. In contrast, the coefficient for Experiment 5 response times to word targets is well outside the cluster, reflecting our interpretation for a lexically mediated effect in this experiment only. The occasional slight departure from zero in some tests is best interpretable in terms of random variation, as expected for such coefficients, which is the reason that studywise correction for Type I error probability is typically advised. Thus we are confident in disregarding occasional effects with $p > .005$ without further interpretation.

General Discussion

In a set of five lexical decision experiments using both spoken and written targets as well as intra- and cross-modal primes we have not obtained a stress priming effect. That is, words (or pseudowords) were not responded to faster when preceded by words (or pseudowords, respectively) with the same stress pattern, or more slowly when preceded by items with a contrasting stress pattern. A priming effect emerged only in Experiment 5, in which primes and targets were segmentally matched as well. Therefore, on the whole, these experiments provide no evidence to support the notion of activation of stress templates per se. Instead, we suggest that stress effects in spoken word recognition reflect prosodic property matching and that there are no true (phonological) stress effects in word recognition unless task-related output representations are involved.

Although linguistic analysis demonstrates the theoretical necessity of lexical stress representations, the psycholinguistic nature of these representations remains unclear. Priming offers a way to address this issue: If a stress template is activated in word recognition it should prime the recognition of subsequent stress-matching words, within or across modalities. However, no priming was found in our experiments within either modality (auditory or visual) or across modalities, in either direction. In the following we consider three alternative explanations for these findings, contrasting (a) a process-type account, according to which abstract stress representations are operative in speech production but are not necessarily activated in word recognition; (b) a representational account, according to which lexical stress is an integral part of specific word representations in the mental lexicon and is not represented as abstract metrical templates shared across words; and (c) a task-specific account, according to which lexical decision with onset-matched primes is not appropriate for revealing abstract stress representations. These three accounts are not mutually exclusive.

Processing considerations

Several studies have produced stress effects using tasks involving speech production (Colombo et al., 2014; Colombo & Zevin, 2009; Sulpizio et al., 2012; Sulpizio & Job, 2015), thereby implicating output processes to account for the findings. Taken together with a sizeable body of literature in which linguistic data are interpreted on the basis of metrical templates (e.g., Hayes, 1995; McCarthy & Prince, 2001), these studies can be taken to imply that abstract stress patterns are operative in speech production. Indeed, stress priming findings in Italian have been attributed to the phonological output stage (Sulpizio et al., 2012; Sulpizio & Job, 2015) and have been explicitly modeled with the CDP++ model of reading aloud (Perry, Ziegler, & Zorzi, 2010, 2013, 2014) at the level of stress output nodes, which receive activation from both the lexical and the sublexical route. Notably, in the study of Colombo and Zevin (2009) stress priming was induced by pseudoword production, indicating an activation of metrical patterns that were not merely abstract but also clearly nonlexical, consistent with the existence and activation of stress nodes in the sublexical route of CDP++. In contrast, there was no such effect with pseudowords in our experiments, consistent with the crucial distinction between lexical and output representations.

Claims about theoretical linguistic representations are not necessarily contiguous, or even compatible, with psycholinguistic concerns over cognitive representations and processes. What is at issue here is the nature of stress representations that are posited to apply in production processes, as found in models such as WEAVER++ (Levelt et al., 1999) and CDP++ (Perry et al., 2010). Although pure metrical priming is not clearly established to occur in speech production (Roelofs & Meyer, 1998; Schiller, Fikkert, & Levelt, 2004), thus complicating the output situation as well, other metrical effects in speech production overall seem well established.

Output processes have been implicated in "implicit prosody" effects found in silent reading using eye movement measures. Specifically, Ashby and Clifton (2005) observed more and longer fixations to words with two stressed syllables compared to words with one stressed syllable, and attributed the difference to "inner speech processes… involv[ing] the assembly and unpacking of phonological information" (p. B96). Breen and Clifton (2011) reported disruptive effects of words with stress patterns that were unanticipated with respect to the local metrical context defined by poetry meter. Moreover, Breen and Clifton (2011, 2013) used garden-path contexts forcing a syntactic reparsing and found longer fixations associated with revisions involving a stress change (e.g., to re-parse the word *abstract* as a verb rather than a noun, compared to a similar re-parse of the word *report*). These effects were attributed to "the creation of an implicit program for subvocalizing" words in silent reading (p. 169), explicitly rejecting an alternative explanation based on perceptual, rather than production, processes.

There is nothing remarkable in suggesting that output (i.e., production) representations and processes may be to some extent distinct from input (i.e.

perceptual) representations and processes. The distinction between input phonology, related to acoustic coding and involved in speech perception, versus output phonology, related to articulatory coding and involved in speech production, is commonplace in neuropsychology (e.g., Corsten, Mende, Cholewa, & Huber, 2007; Howard & Nickels, 2005; Jacquemot, Dupoux, & Bachoud-Lévi, 2007; Szenkovits & Ramus, 2005) and has gained currency in the neuroimaging literature as well (e.g., Hickok & Poeppel, 2004, 2007; Jacquemot & Scott, 2006). We suggest that the distinct requirements of perceptual processes (namely rapid continuous uptake of incoming information) versus production processes (namely hierarchically structured articulatory planning) may implicate different stress-related representations, that is, prosodic characteristics of segments in the former versus abstract metrical templates in the latter. Because our focus is on the perceptual aspect of lexical access, we will not attempt to elaborate on speech production processes and the representations involved in them, which concern a largely nonoverlapping literature.

Abstract metrical representations

Previous studies, reviewed in the introduction, have revealed stress effects that may be conceived of as reflecting abstract stress representations. However, as noted, all of the positive findings can be attributed to either lexical or output representations. For example, in the fragment priming studies (as in our Experiment 5) stress-matching fragments were identical with target word onsets. Therefore the simplest explanation for the priming effect is that the fragment activated the target by perfectly matching its onset. In contrast, stress-mismatching fragments are similar but not identical to the target because of (subphonetic) prosodic differences related to the realization of the stressed syllable. In this case the target is activated comparatively less and the priming effect ensues. This interpretation can be applied to studies presenting two-syllable fragments (Cooper et al., 2002; Soto-Faraco et al., 2001; Tagliapetra & Tabossi, 2005; van Donselaar et al., 2005) or single syllables (Friedrich et al., 2004; Schild et al., 2014a, b) and is supported by eye-movement studies tracking the course of lexical activation during presentation of the prime (Jesse & McQueen, 2014; Reinisch et al., 2009; Sulpizio & McQueen, 2012).

Prima facie, the interpretation of an abstract metrical match for fragment priming experiments appears reasonable for languages such as English or Dutch, where metrical feet are typically aligned to word onsets. However, it is undermined by findings in languages such as Spanish, Italian, or Greek, in which lexical stress falls on one of the last three syllables in a word, regardless of how many syllables may precede it. In these languages stress match or mismatch is relative to the end of the word. This is quite unlike the regular foot structure of English, in which a word-initial trochee is followed by more trochees, in an alternation of strong and weak syllables (Hayes, 1995, ch. 2). In the case of English, a fragment such as /æd.mɪ/ constitutes a trochee and matches the metrical structure at the onset of the word "admiral." However, in Greek, a fragment such as /fi.ða/ defines a final-syllable stress pattern and therefore does not match the metrical structure of the word "φιδάκι" /fi.ða.ci/ (see Table 2). Rather, it matches the word beginning prosodically in that the first two syllables carry acoustic features that correspond to an unstressed syllable followed by a stressed syllable. This kind of analysis is appropriate for Spanish and Italian as well.[7] A prosodic match is also present in the English and Dutch cases, confounded with the metrical match. For a parsimonious

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[7] There is no consensus regarding how such patterns are analyzed. According to Arvaniti (2007), /fi.ða/ is composed of an unmetrified first syllable followed by a degenerate foot made up of the stressed syllable alone (but cf. Malikouti-Drachman & Drachman, 1989). This is consistent with analyses for Italian (e.g., D'Imperio & Rosenthal, 1999) and Spanish (Harris, 1983; Hayes, 1995).

cross-linguistic account, fragment priming findings may need to be reevaluated and reinterpreted as indicative of prosodic, rather than metrical, matches.

Similarly, ERP studies of stress violations (e.g., Domahs et al., 2014; Knaus et al., 2007) and metrical expectations in spoken language processing (e.g., Rothermich et al., 2010; Schmidt-Kassow, & Kotz, 2009; Schmidt-Kassow et al., 2011) can be interpreted on the basis of lexical inhibition due to stress cue mismatch, effects of explicit stress judgments, and supralexical rhythmic effects of the acoustic speech signal, none of which involve abstract metrical frames. Moreover, the finding that prosodically matching but segmentally mismatching single syllables produced slight but measurable ERP effects, however inconsistent across studies (Schild et al., 2014a, b), is also easier to reconcile with acoustic (i.e., in these experiments, pitch-based) rather than abstract (metrical) comparisons. Schild et al. used monosyllabic primes, which are, by definition, insufficient to activate, and thereby prime, a stress pattern, because stress patterns are defined as contrasts between two or more syllables within metrical templates (Ladd, 2008; Liberman & Prince, 1977). No contrasts can be defined within single syllables. However, prosodic properties such as pitch may be associated with stress patterns in certain intonational and phrasal contexts (cf. Brown et al., in press) and may be processed online to match or mismatch lexical representations. Thus, despite mention of “stress priming” (esp. in Schild et al., 2014b), the overall conclusion may be recast as reflecting “prosodic processing” (as in Schild et al., 2014a), making neither implicit nor explicit reference to abstract stress patterns. Indeed, the theoretical interpretations considered by Schild et al. (2014a) did not concern abstract metrical templates but “phoneme-free” prosodic representations, that is, representations of prosodic acoustic cues (specifically, pitch) that may contribute to word identification.

Moreover, ERP results are not only variously inconsistent, but also very difficult to interpret in terms of their functional origin. Even if a purely prosodic ("phoneme-free") mismatch effect can be reliably established, there is no guarantee that it reflects processes directly involved in lexical activation or lexical access, in the absence of behavioral effects clearly implicating words. For example, prosodic properties may be evaluated extralexically, for paralinguistic processing. Therefore such findings are not informative regarding the activation or representation of prosodic or stress patterns in the mental lexicon.

The dominance of specific lexical items, rather than abstract templates, in the activation of stress patterns in Greek is also suggested by pseudoword reading experiments with children and adults (Protopapas & Gerakaki, 2009; Protopapas, Gerakaki, & Alexandri, 2006, 2007). Specifically, when faced with a pseudoword that differs minimally from a known word (usually by a single letter), Greek readers from Grade 2 through adulthood preferentially assign the stress pattern of the known word even when it conflicts with the stress diacritic clearly displayed on the pseudoword. The purported "default" penultimate-syllable stress pattern applies only in the absence of both lexical and orthographic information, that is, when the pseudoword neither resembles a specific word nor bears a diacritic. In this light one can reinterpret the stress assignment data from Italian reading studies, which typically show strong effects of stress neighborhoods rather than of a dominant pattern (e.g., Burani & Arduino, 2004; Burani, Paizi, & Sulpizio, 2014; Colombo & Sulpizio, 2015; Colombo et al., 2014; Giraudo & Montermini, 2010; Sulpizio, Arduino, Paizi, & Burani, 2013; Sulpizio & Colombo, 2013; see Sulpizio, Burani, & Colombo, 2015, for a review). Specifically, these results can be seen as arising from cumulative lexical activation due to similarity in word endings rather than as a result of abstract stress patterns. Alternatively, they may be attributed to sublexical assembly affecting output processes, as in the CDP++ model

(Perry et al., 2014). Notably, effects of dominance, rather than consistency, were observed in lexical decision (Colombo & Sulpizio, 2015), underscoring the distinction between tasks involving production and tasks that do not.

The word-specific, rather than abstract metrical, representation of lexical stress may also account for an effect observed with Greek children in the elementary grades, namely that words carrying an inappropriate diacritic (on the vowel of an unstressed, rather than the stressed, syllable) were read more slowly than words with the diacritic appropriately placed, but words without a diacritic were read equally fast (Protopapas & Gerakaki, 2009). The omission of the diacritic is a frank spelling error and arguably deprives the printed word of its stress information, if we assume that a metrical frame must be constructed based on the position of the diacritic. However, this does not seem to be the case; instead, the patterns of stress assignment findings in Greek reading have been interpreted as consistent with the dominance of a lexical source (Protopapas, 2016; cf. Revithiadou, 1999). That is, words are mainly recognized on the basis of the letter sequence and stress is assigned in the mental lexicon. This processing route obviates the need for abstract metrical frames to be built and applied over syllabified segmental templates. It also means that the role of the diacritic is limited to being a minor orthographic cue to word identity, jointly with the letters, and not a critical cue specific to stress assignment. Absence of the cue does not hamper processing as long as no ambiguities arise (as in the reported experiment). However, a misplaced cue conflicts with the lexical orthographic representation, causing a small delay. According to this interpretation, the diacritic is relatively ineffective in the sublexical processing route. Thus, in the context of word reading models such as the CDP++ we would expect the stress output nodes to be only minimally affected by the diacritic and primarily driven by the lexical route.

In conclusion, the issue of lexical stress representations is far from resolved. In the domain of visual and spoken word recognition no existing data seem to compel an interpretation involving abstract metrical templates. There is no evidence that metrical representations, computed from either visual or auditory input, are abstracted away from specific prosodic cues and specific lexical items. That is, no entities of the form ['σ σ] seem to be involved in accessing the mental lexicon. Rather, our review of the literature indicates that it is prosodic property matching that mediates the observed "stress" effects in online processing, across languages, regardless of the number of syllables. It remains unclear whether prosodic representations in perceptual processing are tied to segmental specification (e.g., [long a] vs. [short a]) or can operate somewhat independently (e.g., [+long]). Certain findings from ERP seem consistent with the latter option, but so far they have not formed a coherently interpretable body of evidence across studies and modalities.

Methodological issues

Before concluding against the involvement of abstract metrical templates in word recognition, additional methodological scrutiny is warranted. Specifically, is priming strongly expected to arise in a lexical decision task on the basis of shared stress representations? Priming studies are ubiquitous in psycholinguistics and constitute a frontline of evidence concerning shared or associated representations. Lexical decision tasks, in particular, are preferred over alternatives such as naming when the burden of articulatory planning and associated output processes is to be avoided. Lexical decision has long been successfully employed to reveal shared representational elements, such as morphemes, under conditions of priming (Diependaele, Grainger, & Sandra, 2012; Goldinger, 1996; Marslen-Wilson, 2007). If abstract metrical templates are part of lexical representations and can be activated in word recognition then we expect them to be subject to priming within the context of a lexical decision task. The additional decision-related overhead of lexical decision that can be a cause for concern in certain theoretical situations (Gomez, 2012) does not affect the plain rationale of our study, which capitalizes on the notion of shared representations among primes and targets. Other tasks, such as rhyming judgments, might be possibly used but would not be unambiguously interpretable because stress is an inherent component of rhyming in Greek and the explicit attention to rhymes could arguably cause the formation and conscious manipulation of task-induced representations that may not be naturally activated in implicit word recognition.

An important aspect of our study is that it did not include only a single experiment, which might be criticized for too long or too short SOA or some other parametric choice. Instead, over five experiments, within and across modalities, there was no hint of stress priming, including auditory-prime conditions in which it is established in the literature that stressed-syllable information affects lexical access as soon as it arrives. Focusing on Experiment 4, in particular, it seems compelling to accept that stress representations may not be necessarily activated in word recognition.

A concern that might arise in the interpretation of our findings relates to the potential effects of lexical inhibition. Specifically, the possibility remains that abstract metrical templates were activated and primed but this was not observed because the target words were inhibited by the primes due to competition at the lexical level. If the prime effectively inhibits the target, due to the shared onset but mismatching ensuing segments, before (or more strongly than) the shared stress pattern can facilitate target processing, then stress priming cannot occur. Such an interpretation, primarily concerning Experiments 2 and 4 (with auditory primes), would be consistent with a view of incremental spoken word recognition involving rapid inhibition of segmentally mismatching candidates (see McQueen, 2007, for review and discussion). The plausibility of this suggestion seems limited in light of the strong priming effects obtained in other cases of shared representations, despite common word onsets, such as in semantic or morphological priming (e.g., Rastle & Davis, 2008; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; cf. Gonnerman, Seidenberg, & Andersen, 2007). The timing of stimuli in our experiments, at least for visual primes (effective SOA around 100 ms in Experiment 1b and fixed SOA of 133 ms in Experiment 3) was arguably too long for orthographic facilitation to occur and too short for inhibition to arise, providing a potentially clear temporal window for stress priming effects to be observed. Moreover, the availability of cohort neighbors (such as our target stimuli) for further consideration in spoken word recognition, including the possibility of stress pattern priming past the point of segmental mismatch, is consistent with rhyme activation (Allopenna, Magnuson, & Tanenhaus, 1998) and with recent ERP data interpreted as indicative of "extended parallel processing" (Friedrich, Felder, Lahiri, & Eulitz, 2013).

More specifically regarding auditory word recognition, Dufour (2008) reviewed the literature and noted that phonological facilitation may occur with a small initial overlap (1–2 phonemes) between prime and target words and inhibition when all except the last phoneme overlap (3-4 phonemes for single-syllable words). For our word stimuli, most prime-target pairs had a 2-phoneme overlap ($M = 2.48$, $SD = 0.67$), on average making up only 37.9% of the target length (6–7 phonemes over 3 syllables). Thus our stimuli are closer to "initial phonemes" than to "most phonemes" and, according to this review, no inhibition should be expected in Experiment 4. At any rate, because all words in each group had the same first syllable, equal inhibition should occur in the stress-congruent and stress-incongruent conditions in each experiment. If there were any differential facilitation on the basis of the stress pattern it could have surfaced over the common baseline of inhibition.

Moreover, the explanation implicating lexical inhibition must involve lexically represented stress patterns and not abstract supra-lexical frames because there was no stress effect for the pseudowords in our experiments. In other words, if lexical inhibition is invoked as an explanation for the lack of stress priming with word stimuli, we are left without an explanation for the lack of stress priming with pseudoword stimuli, in which lexical inhibition is out of the question. Arguably, if abstract stress patterns are computed on the basis of input features, then they should also be operative in the case of pseudowords. Indeed, Colombo and Zevin (2009) documented stress priming effects in word production arising by pseudoword primes. That is, pseudoword production can induce activation of stress patterns that affect word production. This cannot be explained by recourse to lexical representations. Therefore, the interpretation dismissing our null findings as due to masking of stress priming by lexical inhibition fails to achieve explanatory parsimony with previous studies. Instead, attribution of stress effects to output representations seems to account more parsimoniously for the data, and has been successfully implemented in modeling such effects in Italian with the CDP++ (Perry et al., 2014; Sulpizio & Job, 2015).

Logically, absence of evidence does not constitute evidence of absence. Therefore, the possibility cannot be conclusively refuted that methodological factors related to the administered tasks (such as lexical inhibition) may have precluded or masked the emergence of stress priming effects. However, this would constitute idle criticism in the absence of positive evidence from other tasks, or tasks with different parameter settings, consistent with the activation of abstract metrical templates in word recognition—not attributable to lexical activation or to speech production processes. As we have argued above, no such evidence can be found in the literature.

Therefore, given the prima facie plausibility of the priming rationale offered in the introduction, we contend that the relegation of the lack of stress priming effects to trivial methodological failures may be premature.

Limitations and Conclusion

It may be recalled that effects of stress position were obtained in Experiments 2 (marginally), 3, 5, in which targets were presented visually. Specifically, words with penultimate-syllable stress were responded to faster and more accurately than words with antepenultimate-syllable stress. In addition, in Experiments 3 (marginally) and 5, pseudowords with penultimate-syllable stress were responded to more slowly than words with antepenultimate-syllable stress. This effect occurred for visual targets only, but was obtained across priming conditions and even in the presence of (lexically mediated) stress priming (in Experiment 5), therefore it seems to be a robust effect pertaining to this stimulus set. We have chosen not to discuss this effect above because it was a post-hoc observation that does not relate to our research question (which specifically concerns the involvement of abstract stress templates in word recognition, to be revealed with stress priming). Both penultimate- and antepenultimate-stress targets were included in the experiments, in order to test whether stress priming effects would occur regardless of stress position, with potential implications regarding stress representations. In this context, a main effect of stress position is irrelevant and uninformative. However, it did emerge as a consistent finding, perhaps interpretable as a default (or dominant) stress effect. Colombo and Sulpizio (2015) reported a similar finding for lexical decision in Italian, and attributed the effect to cumulative activation in the phonological lexicon, driven both by faster access to lexical phonological representations and by feedback activation from sublexical contributions. Although there is some evidence for the operation of a default stress pattern in Greek naming tasks, noted previously, to our knowledge this is the first finding consistent with a default pattern in a task not involving speech production. Further research is required to examine the origin and nature of this effect.

A potential objection might be raised concerning our choice of language, to the effect that our results may not generalize across languages. Indeed, the specific phonetic and phonological properties of stress vary substantially across languages, so that universal conclusions may be strictly impossible. Findings from the psycholinguistically dominant English language, in particular, may be especially unsuitable for cross-linguistic comparisons and generalizations, due to the confound between segmental and prosodic cues in terms of vowel quality. Nevertheless, our findings are in line with the cross-linguistic situation as reviewed in the introduction and argued above. In our view, Greek possesses features that make it uniquely appropriate for studies of lexical stress without obvious causes for concern regarding generalizability.

In conclusion, we did not observe stress effects in a series of priming experiments, disconfirming predictions arising from a hypothesis of abstract metrical templates. This does not prove that metrical templates do not exist, or even that they do not participate in lexical access, but it does transfer the onus to proponents of linguistic theories positing such templates as underlying lexical stress distinctions in word recognition to produce relevant psycholinguistic evidence, through priming or other means. Other functions of lexical stress in word processing, such as lexical segmentation (e.g., Mattys, 2004; Mattys, White, & Melhorn, 2005), are compatible with the suggestion of nonabstract representations insofar as they can be attributed to prosodic acoustic cues in the signal or word-specific properties of representations in the mental lexicon. The contemporary view of online uptake of prosodic cues rapidly contributing to lexical activation and competition (e.g., Brown et al., in press; Reinisch et al., 2009; Schild et al., 2014a; Sulpizio & McQueen, 2012) is also entirely consistent with our findings. The psycholinguistic question regarding the nature of lexical stress representations in word recognition remains to be addressed.

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Table 1

Mean values for lexical and sublexical variables characterizing the stimuli and comparisons between words vs. pseudowords and between items stressed on the penultimate vs. on the antepenultimate syllable.

	Words					Pseudowords					Words vs. Pseudowords					
	Stressed syl.		Pen. vs. Ant.			Stressed syl.		Pen. vs. Ant.			Pen.			Ant.		
	Pen.	Ant.	*t*	*p*	*d*	Pen.	Ant.	*t*	*p*	*d*	*t*	*p*	*d*	*t*	*p*	*d*
Log frequency	−1.52	−1.63	0.53	.60	0.10											
N letters	6.75	6.75	0.00	1.00	0.00	6.77	6.75	0.13	.90	0.02	0.13	.90	0.02	0.13	.90	0.02
N phonemes	6.55	6.55	0.00	1.00	0.00	6.55	6.55	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00
Bigram frequency	1.03	1.04	−0.14	.89	−0.03	1.04	1.04	−0.02	.99	0.00	−0.02	.99	0.00	−0.02	.99	0.00
Syllable frequency	8.94	7.92	1.34	.18	0.24	7.97	8.63	−0.79	.43	−0.14	−0.79	.43	−0.14	−0.79	.43	−0.14
Ph. neighbors	4.13	3.98	0.29	.77	0.05	2.37	2.62	−0.56	.58	−0.10	−0.56	.58	−0.10	−0.56	.58	−0.10
Or. neighbors	2.02	1.98	0.11	.91	0.02	0.95	0.95	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00
Hi−F ph. neighbors	2.28	2.53	−0.67	.50	−0.12	2.37	2.62	−0.56	.58	−0.10	−0.56	.58	−0.10	−0.56	.58	−0.10
Hi−F or. neighbors	1.17	1.17	0.00	1.00	0.00	0.95	0.95	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00
OLD20	1.98	1.98	−0.02	.99	0.00	2.29	2.34	−0.63	.53	−0.11	−0.63	.53	−0.11	−0.63	.53	−0.11
OLD20(bf)	3.33	3.43	−1.22	.22	−0.22	3.50	3.36	1.56	.12	0.28	1.56	.12	0.28	1.56	.12	0.28

Note. Syl. = syllable; Pen. = penultimate syllable stress; Ant. = antepenultimate syllable stress; N = number; Ph. = phonological ; Or. = orthographic; Hi-F = high frequency; OLD = orthographic Levenshtein distance; bf = base forms only; *d* is Cohen’s index of effect size.

Table 2

An example matched word-pseudoword set including a six-word group and a six-pseudoword group, with associated properties.

Item	Orth	Lex	Phon	Gloss	StrPos	Freq	BigrF	SylF	OLD20
W1	φιδάκι	W	fiðaci	little snake	Pen	0.372	0.254	2.777	2.35
W2	φυλάμε	W	filame	we guard	Pen	0.338	0.447	7.761	1.80
W3	φυσάμε	W	fisame	we blow	Pen	0.101	0.340	6.778	2.10
W4	φίλαγε	W	filaʝe	s/he was kissing	Ant	0.135	0.363	2.356	1.90
W5	φίμωση	W	fimosi	muzzling	Ant	0.372	0.375	9.740	2.05
W6	φύγατε	W	fiɣate	you$_{pl}$ left	Ant	0.981	0.420	4.840	1.75
P1	φιλέγα	P	fileɣa	–	Pen	–	0.355	1.739	2.40
P2	φιμώγα	P	fimoɣa	–	Pen	–	0.158	1.725	3.00
P3	φυτάση	P	fitasi	–	Pen	–	0.643	10.106	2.60
P4	φίσακι	P	fisaci	–	Ant	–	0.500	3.212	2.85
P5	φύμελα	P	fimela	–	Ant	–	0.545	7.624	2.65
P6	φίδαμε	P	fiðame	–	Ant	–	0.471	6.928	2.00

Note. All items in this set begin with a /fi/ syllable and have a CV.CV.CV structure with six phonemes spelled with six letters. Orth = orthographic spelling; Lex = lexicality (Word, Pseudoword); Phon = phonetic pronunciation; StrPos = stress position (Penultimate, Antepenultimate syllable); Freq = printed frequency (per million tokens); N let = number of letters; N phon = number of phonemes; BigrF = log mean letter bigram frequency (letters & spaces); SylF = log mean phonological syllable frequency; OLD20 = mean orthographic Levenshtein distance of 20 nearest neighbors. This particular set was selected for illustrative purposes on the basis of the translatability of the word items.

Table 3

Assignment of individual words and pseudowords within each 6-item group to prime/target conditions distributed among lists

	StrPos		List 1		List 2		List 3		List 4		List 5		List 6	
Lex	Prime	Target	Prime	Target	Prime	Target	Prime	Target	Prime	Target	Prime	Target	Prime	Target
W	Pen	Pen	W2	W1	W3	W1	W1	W2	W3	W2	W1	W3	W2	W3
W	Ant	Pen	W6	W1	W5	W1	W6	W2	W4	W2	W5	W3	W4	W3
W	Ant	Ant	W5	W4	W6	W4	W4	W5	W6	W5	W4	W6	W5	W6
W	Pen	Ant	W3	W4	W2	W4	W3	W5	W1	W5	W2	W6	W1	W6
P	Pen	Pen	P2	P1	P3	P1	P1	P2	P3	P2	P1	P3	P2	P3
P	Ant	Pen	P6	P1	P5	P1	P6	P2	P4	P2	P5	P3	P4	P3
P	Ant	Ant	P5	P4	P6	P4	P4	P5	P6	P5	P4	P6	P5	P6
P	Pen	Ant	P3	P4	P2	P4	P3	P5	P1	P5	P2	P6	P1	P6

Note. Lex = lexicality, W= word, P= pseudoword, StrPos = stress position, Pen=penultimate syllable, Ant=antepenultimate syllable.

Words W1–W3 and pseudowords P1–P3 are stressed on the penultimate syllable; W4–W6 and P4–P6 on the antepenultimate syllable (cf. Table 2).

Table 4

Duration, fundamental frequency, and intensity for each syllable of word and pseudoword stimuli used as targets and/or primes in Experiments 1a, 1b, 2, and 4

	Antepenult				Penult				Final			
	StrPen		StrAnt		StrPen		StrAnt		StrPen		StrAnt	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Words												
Duration (ms)	169.3	55.9	210.0	61.8	228.1	43.5	171.8	36.1	224.8	47.1	200.9	42.8
F_0 (Hz)	96.2	3.8	121.9	7.8	115.1	6.7	97.9	4.4	93.1	7.0	83.1	3.2
Intensity (dB)	73.3	3.5	79.7	2.3	77.5	2.5	73.4	3.7	69.5	3.6	66.5	3.0
Pseudowords												
Duration (ms)	164.3	57.6	205.3	58.2	229.3	38.7	171.6	31.2	219.1	38.2	200.1	49.6
F_0 (Hz)	96.6	4.5	123.7	8.8	115.3	6.1	99.3	5.2	92.1	7.0	84.2	3.9
Intensity (dB)	73.4	3.0	79.8	2.4	77.9	3.1	73.4	3.4	70.5	3.1	66.2	3.5

Note: F_0, fundamental frequency. StrPen, penultimate syllable stress items; StrAnt, antepenultimate syllable stress items. For each syllable in each item, F_0 and intensity were obtained using the “Get mean…” Praat function of the Pitch and Intensity contour, respectively, over the marked duration of the syllable.

Table 5

Duration, fundamental frequency, and intensity for each syllable of the two-syllable fragment primes used in Experiment 5

	First syllable				Second syllable			
	StrPen		StrAnt		StrPen		StrAnt	
	M	SD	M	SD	M	SD	M	SD
Primes to word targets								
Duration (ms)	166.2	56.9	205.5	60.0	227.1	43.6	170.5	33.8
F_0 (Hz)	96.6	4.4	122.5	8.7	115.5	6.6	98.9	5.1
Intensity (dB)	73.7	3.4	80.1	2.3	77.9	2.9	73.7	3.6
Primes to pseudoword targets								
Duration (ms)	165.6	56.6	205.1	57.6	227.6	42.6	171.3	31.3
F_0 (Hz)	96.6	4.2	123.3	8.5	116.0	6.5	98.9	5.1
Intensity (dB)	73.7	3.3	80.0	2.2	78.2	3.0	73.7	3.8

Note: Abbreviations and measures as in Table 4.

Figure Captions

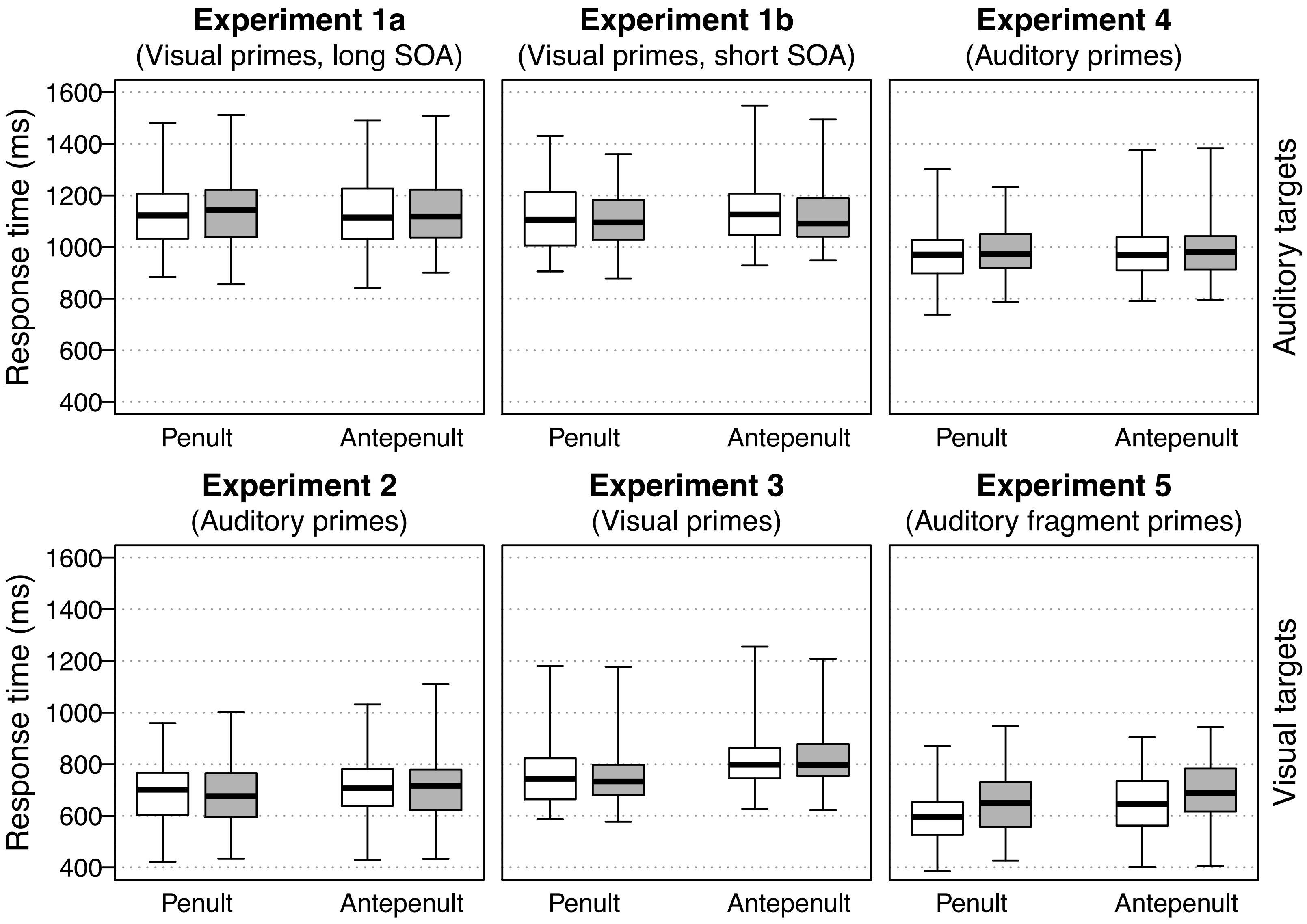
Figure 1. Response times for word targets in all experiments. Each panel displays data (log means per participant) from one experiment, separately for penultimate-syllable stress targets (left) and antepenultimate-syllable stress targets (right) in the stress-congruent priming condition (empty boxes) and the stress-incongruent priming condition (grey shaded boxes). Each box contains 50% of the data (i.e., of participants). The thick horizontal line indicates the median. Whiskers extend to the full range.

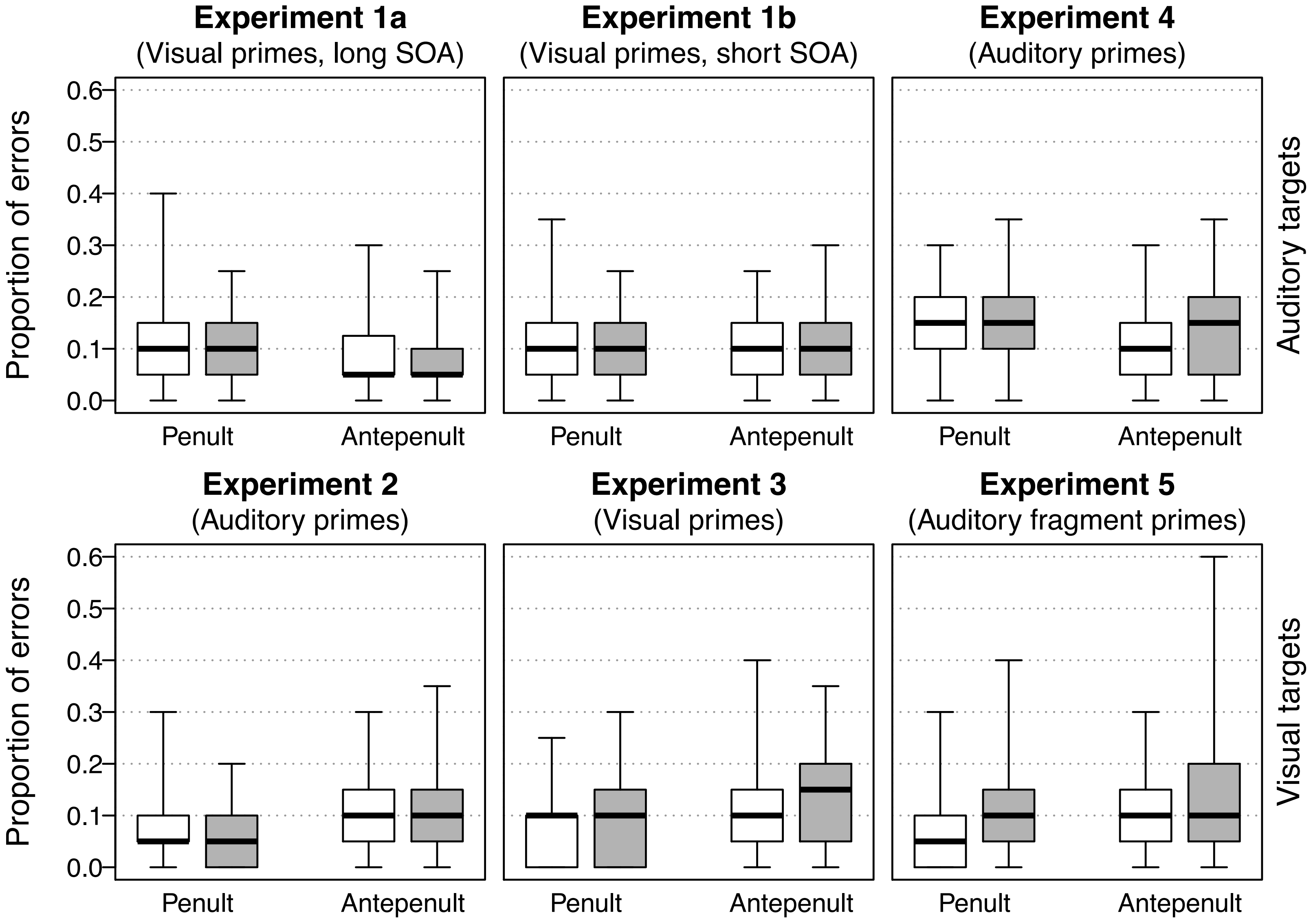
Figure 2. Error proportion for word targets in all experiments. See Figure 1 for explanation.

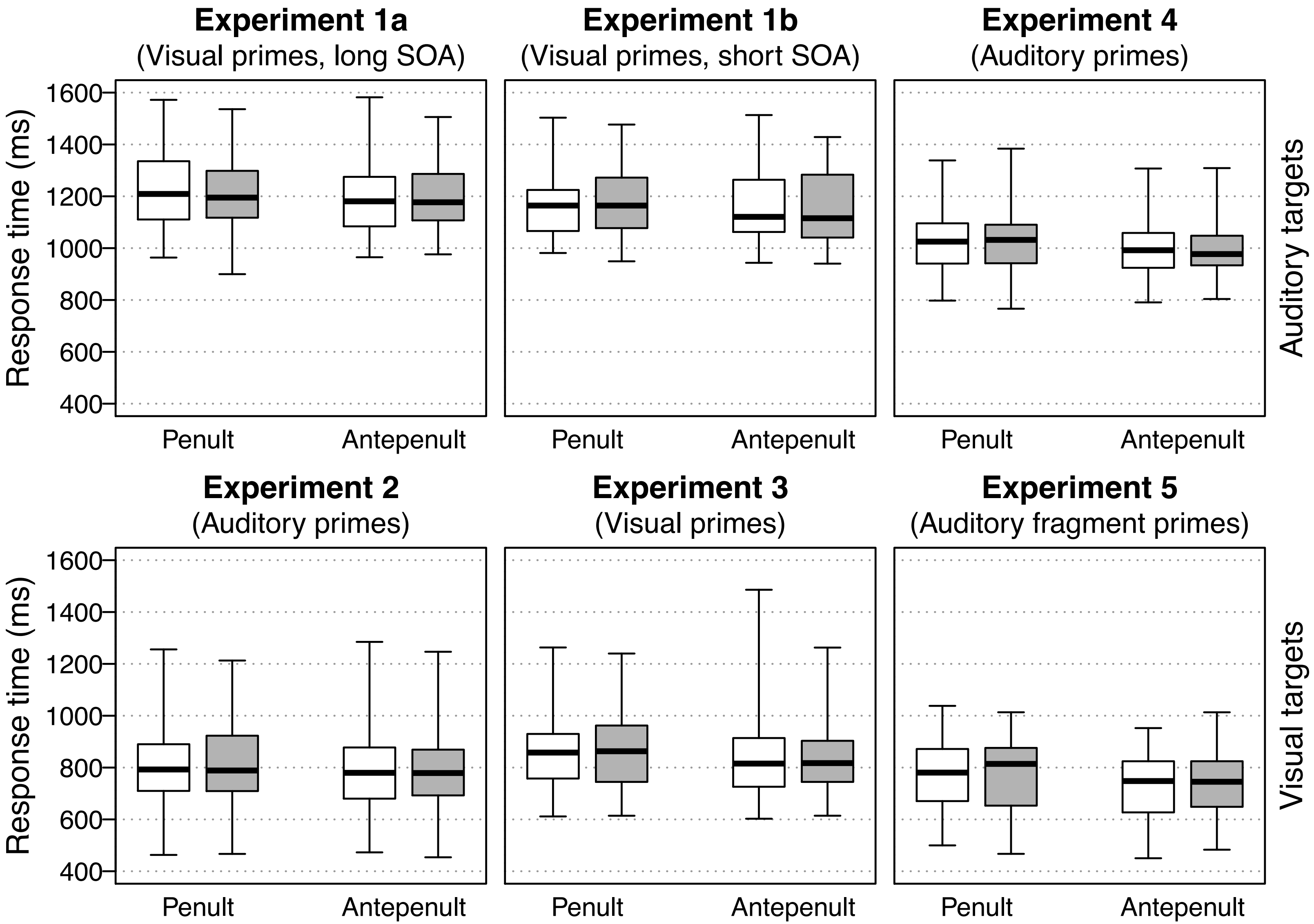
Figure 3. Response times for pseudoword targets in all experiments. See Figure 1 for explanation.

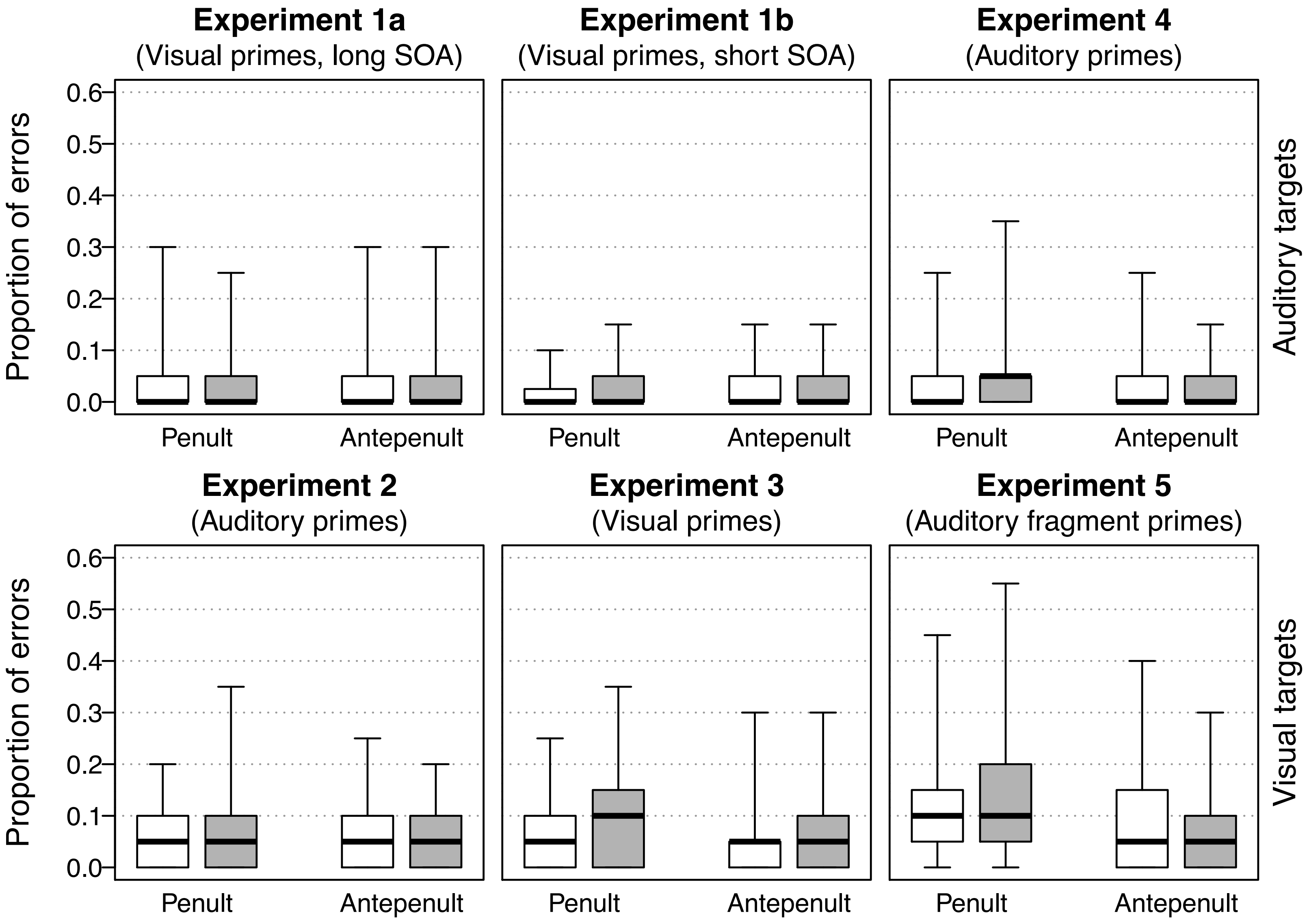
Figure 4. Error proportion for pseudoword targets in all experiments. See Figure 1 for explanation.

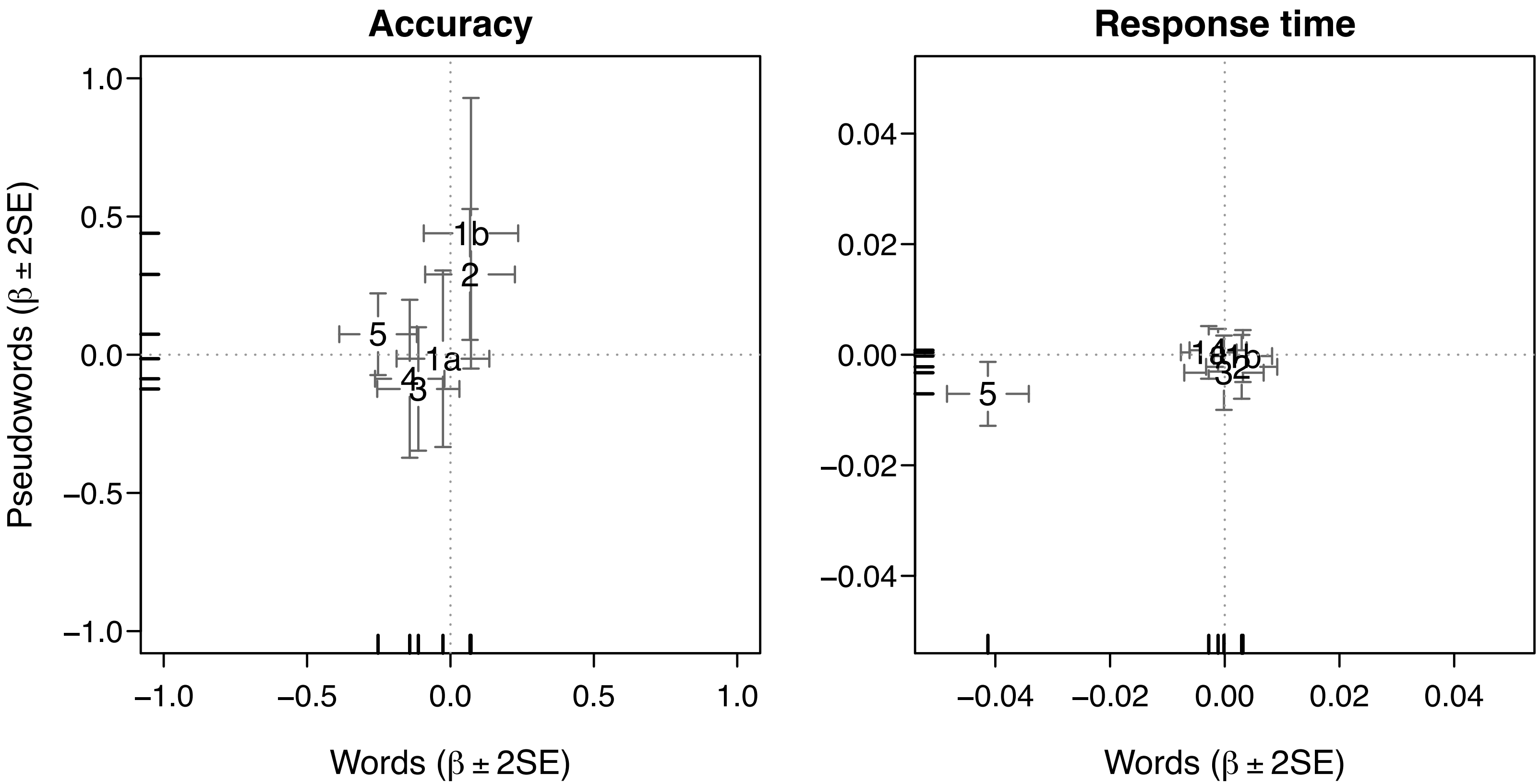
Figure 5. Estimated regression coefficients for the main effect of stress congruence in mixed-effects analysis of error proportion (left) and response latency (right) data in Experiments 1a–5, plotted for pseudowords (on the vertical axis) against words (on the horizontal axis). The position of the estimate is indicated by the corresponding experiment number. Error bars extend to two standard errors.


Experiment 1a
(Visual primes, long SOA)
Experiment 1b
(Visual primes, short SOA)
Experiment 4
(Auditory primes)
Experiment 2
(Auditory primes)
Experiment 3
(Visual primes)
Experiment 5
(Auditory fragment primes)
Response time (ms)
1600
1400
1200
1000
800
600
400
Penult
Antepenult
Auditory targets
Visual targets


Experiment 1a
(Visual primes, long SOA)
Experiment 1b
(Visual primes, short SOA)
Experiment 4
(Auditory primes)
Experiment 2
(Auditory primes)
Experiment 3
(Visual primes)
Experiment 5
(Auditory fragment primes)
Proportion of errors
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Penult
Antepenult
Auditory targets
Visual targets


Experiment 1a
(Visual primes, long SOA)
Experiment 1b
(Visual primes, short SOA)
Experiment 4
(Auditory primes)
Experiment 2
(Auditory primes)
Experiment 3
(Visual primes)
Experiment 5
(Auditory fragment primes)
Response time (ms)
1600
1400
1200
1000
800
600
400
Penult
Antepenult
Auditory targets
Visual targets


Experiment 1a
(Visual primes, long SOA)
Experiment 1b
(Visual primes, short SOA)
Experiment 4
(Auditory primes)
Auditory targets
Experiment 2
(Auditory primes)
Experiment 3
(Visual primes)
Experiment 5
(Auditory fragment primes)
Visual targets
Proportion of errors
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Penult
Antepenult


Accuracy
Response time
Pseudowords (β ± 2SE)
Words (β ± 2SE)
Words (β ± 2SE)
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
0.04
0.02
0.00
−0.02
−0.04
−0.04
−0.02
0.00
0.02
0.04
1b
2
5
1a
4
3
1a
4
1b
3
2
5