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Production priming of stress in nonwords

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In this study, we demonstrate production-to-production priming of stress in nonwords, when participants must assign a stress pattern without reference to lexical information. This priming effect is boosted when segmental material overlaps between prime and target, but is robust even when no segmental material overlaps. We argue that stress patterns are represented in the minds of speakers, independently from segmental representations. These independent stress representations must be active alongside segmental representations during production.

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1. Introduction

Word-stress in many languages is not completely predictable and must be memorized for each word. For example, in English the word REcord has a different meaning from the word reCORD, though they differ only in their stress pattern (capital letters indicate stressed syllables). In languages like this, speakers must recognize different stress patterns produced over similar segmental material, represent them, and ultimately store stress in lexical entries. How stress is represented in perception, production, and in the lexicon is still an open question, with evidence supporting both structural representations like metrical feet (Domahs, et al., 2008; Hayes, 1995), or metrical frames (Levelt et al., 1999), and featural or even phonetic representations localized to a particular segment (Protopapas et al., 2016). Independent representations of stress, which do not refer to segments, seem to be necessary for adequately representing speakers' knowledge of the stress rules of their language, but evidence for their involvement in online speech processing or production is mixed. While previous studies of event-related potentials (ERPs) in processing, and errors in production, show evidence for online activation of independent stress representations, studies of priming effects on reaction times typically find effects only when segmental material overlaps substantially between prime and target. In this paper, we find self-priming (production-to-production) of stress when participants produced a sequence of nonwords. We argue that our production paradigm demonstrates a role for abstract representation of stress in production. Stress may, in fact, behave similarly to syntactic structure in priming studies, showing weak or no effects on reaction times, but stronger effects on participants' choices of structure.

Previous studies consistently show that stress information is used in lexical access in concert with segmental information. Stress priming can be seen in lexical decision tasks so long as there is substantial segmental overlap between prime and target. Soto-Faraco et al. (2001) used cross-modal priming in a lexical decision task to study effects of stress on lexical access in Spanish. Their participants recognized visually presented target words more slowly and with more errors when they were preceded by an auditory fragment that mismatched in stress than when they were preceded by a fragment that matched in stress. Importantly, these fragments also matched in segmental material. An example from the study is the target word PRINcipe, preceded either by the fragment PRINci- (matching) or by the fragment prinCI (from the word prinCIpio, mismatching). Since the priming fragments differ only in stress, the slowdown for prinCI-PRINcipe must indicate that speakers are using the stress pattern to conduct lexical access on PRINcipe and experience interference when the stress pattern does not match. Gutiérrez-Palma and Palma-Reyes (2008) found a similar effect using masked priming with visually presented stimuli in Spanish, at longer SOA intervals (100 ms and 143 ms) but not at shorter intervals (33 ms, 66 ms). In English, Cooper et al. (2002) again used cross-modal priming, finding that both monosyllabic and bisyllabic primes (mus- from MUsic/muSEum; admi- from ADmiral/admiRAtion) facilitates decision times when they matched the target in stress relative to when they did not match. Reinisch et al. (2010), studying Dutch speakers, measured participants' looks to visually presented words when they overlapped in segmental material with an auditory stimulus, but matched or mismatched in stress. Participants' fixations on the word which matched in stress were more frequent than fixations on the word which mismatched in stress, even before any segmental information could disambiguate between them. This indicates that listeners quickly and automatically use stress information to recognize words.

The hypothesis that stress information is used quickly and automatically in lexical access is further supported by priming effects for semantic neighbors of words which match a prime's stress. Tabossi and Tagliapietra (2005) used a cross-modal priming task in Italian, finding again that stress match produced facilitation in lexical decision, even when the stress matched a semantic neighbor of the target and not the actual target (example: the prime [ˈgo.mi] matching *gomito* 'elbow' where the target was target *braccio* 'arm'). In Dutch, van Donselaar et al. (2005) found a similar effect, using cross-modal priming and both monosyllabic and bisyllabic primes. When the prime matched the target in segmental material or a semantic neighbor of the target, they found faster lexical decision times relative to control.

The effect of stress on lexical access is dependent on a word's segmental material. Schiller et al. (2004), looking for influence of an abstract stress representation, examined Dutch speakers' picture-naming reaction times when pictures were preceded by an auditory prime that matched or mismatched in stress only, sharing no segmental material. An example from the paper is a picture of a trout (*foREL* in Dutch), preceded either by the prime *vamPIER* ('vampire', matching), or by KEtel ('kettle', mismatching). In three experiments, they found a priming effect for semantic relatedness (a picture of a trout preceded by *maKREEL*, 'mackerel'), but no priming effect for stress match.

The conclusion from results like that of Schiller et al. (2004) is that while stress is used in lexical access, it is not represented in the lexicon independently of segmental material. One way to represent stress segmentally is through vowel quality alternations between stressed and unstressed syllables. Unstressed vowels are frequently "reduced" to schwa or another short vowel. Consider REcord vs. reCORD in English. The two words could in principle be represented in the lexicon with the same segments and different stress: /rɛ́kɔrd/ vs. /rɛkɔ́rd/. On the surface, however, the two exhibit different sequences of vowels: [ɹə.ˈkɔɹd] vs. [ˈɹɛ.kɹ̩d]. They could just as well be represented in the lexicon with different sequences of vowels and without explicit stress marking: [ɹəkɔɹd] vs. [ɹɛkɹd]. This kind of vowel reduction represents an extreme case where stress need not be represented as its own independent object, either in the lexicon or in perception or production. These representations make sense in English, where vowel reduction is strong, but we might expect to see stress information used differently in languages without vowel reduction. Protopapas et al. (2016) directly tested for stress priming in Greek, a language without vowel reduction. They found in four experiments that abstract stress patterns did not affect reaction times in a visual, auditory, or cross-modal lexical decision task. Only when segmental material matched—in their Experiment 5—did they observe stress priming. From this, they concluded that in Greek as well as Dutch, stress representation is not separable from segmental representation in lexical items.

Although Greek does not have vowel reduction, its stressed syllables are still phonetically distinct from unstressed syllables. As is typical in languages with word-stress, stress is realized as a cluster of phonetic properties, including longer duration, more extreme articulation (more peripheral vowels, for example), lower or higher pitch, steeper or shallower spectral tilt, greater pitch excursions, and greater intensity (Beckman, 1986; Hayes, 1995; Plag et al., 2011). Results from studies like Protopapas et al. (2016) and Schiller et al. (2004) indicate that at least some of these phonetic details must be directly stored in the segments of the lexical item. For example, the [i] of *FImosi*, from Protopapas et al., would differ from the [i] of *fiLAme* in its lexical representation: The stressed [i] would include specifications for long duration, high intensity, and so on, while the unstressed [i] would include specifications for short duration, low intensity, etc.

A few problems arise with this model of stress representation as a general proposal for all languages with word-stress. The first is that the phonetics of stress are typically not stable across contexts or utterances. For example, stressed syllables host pitch accents in many languages, but the actual pitch contour of those accents is determined by the higher level syntactic, semantic and pragmatic context (Arvaniti et al., 1998; Gussenhoven, 2004; Ladd et al., 2000; Ladd, 2008; Pierrehumbert, 1980). Thus, the same stressed syllable may have high pitch or low pitch, depending on context. Additionally, Bosker (2022) demonstrated that Dutch listeners can adapt their expectations about the phonetics of stress, similar to how listeners adapt to segmental productions with unusual phonetics (McQueen et al., 2006). As McQueen et al. argue for segments, this malleability of phonetics for stress supports the existence of an abstract stress specification in the lexicon, independent of specific phonetic details.

More generally, there is evidence that speakers treat stress as an abstract concept in contexts other than lexical access. Speakers may use abstract stress rules to assign stress patterns to novel words (Domahs et al., 2014; Fidelholtz, 1979; Garcia, 2017; Guion et al., 2003; Trammell, 1978; Walch, 1972), sometimes in ways that depend on specific real words in the lexicon (Baker & Smith, 1976). These abstract stress rules can also be used in lexical access (Sulpizio & McQueen, 2012). Listeners can match a stress pattern with no segmental information to a word (Kaland, 2020). Listeners can also use word-stress as a cue to word boundaries, even when they are as young as 9 months (Kabak & Kazanina, 2010; Thiessen & Saffran, 2003).

Finally, some studies have found effects of stress match without segmental match. A few of these found effects in reaction times, but most found effects in other measures, such as production or EEG. Domínguez Martínez and Cuetos Vega (2018) found an effect with reaction times only, in direct contrast to Schiller et al. (2004). They conducted an orthographically-presented masked priming study, measuring lexical decision times. Using a short SOA of 32 ms, they found that stress matching pairs like PERsa/RASgo exhibited facilitation similar to that of segmentally matched pairs (rasGO/RASgo) when compared to unrelated pairs (dorMÍ/RASgo).

Several studies have used event-related potentials (ERP) to examine stress processing. Friedrich et al. (2004), in a cross-modal word fragment priming study in German, found a very small but statistically significant effect on lexical decision times—just 1 ms difference in means when segments did not match. In ERPs, they found a slightly reduced amplitude of the P350, a component related to lexical identification, when primes and targets matched in stress. Schild et al. (2014a) also measured EEG and reaction times during an auditory go/no-go version of lexical decision in German. They found effects in reaction times for segment match and not stress match, but they found differences in ERPs related to stress match. When stress matched but segments did not, they found increased positivity across posterior regions, starting at 200 ms and continuing until 600 ms. This effect was distinct in scalp distribution from the effect of the left-lateralized positivity they observed for phoneme match. In a follow-up study (Schild et al., 2014b), the researchers found no effects of stress match without segment match on reaction times but did find differences in ERPs, which were similar to the first study in timing and distribution but opposite in polarity. Sulpizio, Job, and Burani (2012) and Sulpizio, Vespignani and Job (2016) conducted very similar studies on reading aloud in Italian. Both found naming latencies were longer for words preceded by a prime with matching stress (and which did not match in segmental material). Both studies also found a difference in ERP amplitude between 200 and 400 ms post stimulus onset, when the target was preceded by a prime that matched in stress, compared to a prime that mismatched in stress.

Abstract stress representations can also influence participants' production. Shaw (2012, 2013) examined English-speaking participants' production latency times, stress error rates, and the phonetics of their stress productions in a blocked design. In a speeded production task, participants read aloud three prime words with either trochaic (BAllad) or iambic (beGIN) stress, followed by a target word with iambic stress. Participants made more errors, producing iambic words like forGET as trochees (FORget), when the prime words were trochees, than when they matched the target's iambic stress. Additionally, trochaic errors that were preceded by trochaic primes were produced with shorter latencies than those preceded by iambs. Colombo and Zevin (2009) likewise looked at participants' stress errors in Italian, examining both real words and nonwords. Participants produced real words that are lexically marked for non-dominant stress with dominant stress (incorrect **maCCHIna*, rather than *MAcchina* 'car', for example) more often after producing a nonword with dominant stress than after producing a real word with non-dominant stress.

To summarize, stress is clearly an important element of the lexical access process, but stress priming typically does not shorten reaction times or production latencies in the absence of segmental overlap. When it does, that effect is weak or even reversed, as in the case of Sulpizio et al. (2012, 2016). On the other hand, stress match affects processing differently than segmental match, as we can see from the two distinct ERP components observed in Schild et al. (2014a, 2014b). Stress match can also affect production choices so that participants tend to produce the same stress patterns in a row, even when that leads to errors.

If stress is represented abstractly, why don't we observe priming effects in lexical access tasks, as we do for other abstract phonological and grammatical structures? And if stress is represented phonetically, why are its phonetics so variable, and how do speakers pick up on patterns across their lexicons? One possibility is an intermediate level of abstraction: a feature attached to specific vowels, but not a template across the whole word. In this case, languages would have two versions of each vowel: stressed [á] and unstressed [ă], stressed [í] and unstressed [ĭ], etc. This would be similar to languages with a length distinction, which have long and short versions of each vowel. Such a feature could explain the variable phonetics of stress and how people can learn stress patterns in their language. We will call this the Local Representation Hypothesis.

Another possibility is that speakers do use abstract structural representations of stress, but priming of this representation does not facilitate lexical access tasks unless segments overlap. We will call this the Abstract Representation Hypothesis. One possibility, put forth in Levelt et al. (1999), is that segmental material and metrical structure are accessed in parallel and constrained to take about the same amount of time. Because of this constraint, the lexical access process would be facilitated only if both segmental and metrical material were facilitated. This could explain why primed metrical structure seems to affect stress pattern choices (Colombo & Zevin, 2009) and ERP components (Friederich et al. 2004; Schild et al. 2014ab, and Sulpizio et al., 2012), but not timing. Another possibility is that structural priming affects the production process differently than comprehension more broadly. Priming of syntactic structures tends to be weaker in comprehension than in production and is often found only in the presence of significant lexical overlap between prime and target, called the "lexical boost" (Pickering & Ferreira, 2008; Tooley & Traxler, 2010). Pickering and Ferreira suggest that whatever the effects of structural priming are, they seem to have a greater effect on structural choices (active or passive, for example) than on timing. If the mechanism behind metrical structure priming is similar to that of syntactic structural priming, the same comprehension/production divide might obtain. Whereas Shaw (2012, 2013), and Colombo and Zevin (2009), measured participants' stress choices on real words, we ask participants to produce nonwords whose stress is not known in advance. In the absence of any lexically determined target stress pattern, we expect recently produced stress patterns to affect participants' stress choices more clearly than previously observed.

In the present study, we present participants with novel words of English, withholding information about the stress pattern, and force participants to choose a stress pattern so they can produce the novel word fluently. We expect that, as in Colombo and Zevin's (2009) study, recent stress patterns will influence participants' choices of stress on the novel words. We use nonwords rather than real words to avoid participants' stress choices being dictated by lexical listing. The task is fundamentally about choosing a stress pattern, not about accessing lexically stored material. Nonwords are presented continuously in our study, without participants being aware of any prime-target structure. If the local representation hypothesis is correct, then the immediately preceding trial should not affect participants' stress choices unless the two novel words share segmental material. However, if the abstract representation hypothesis is correct, then we expect an effect of the immediately preceding trial on every novel word production, regardless of any segmental match.

We expect that regularities in the lexicon of English will also affect participants' stress choices. In English, the most general statistical regularity about stress is that it most often appears on the first syllable of the word (Cutler & Carter, 1987). This is modulated by syntactic category, with nouns nearly always taking stress on the first syllable, and verbs often taking stress on the second, or final, syllable (Kelly & Bock, 1988). Both generalizations are primarily true of two-syllable words. English verbs longer than two syllables generally contain at least one suffix, which often dictates the stress pattern and makes generalized rules or statistical regularities difficult to discern. In nouns and adjectives with three syllables or more, stress is dependent on syllable weight. When the word's penultimate syllable is heavy, meaning its nucleus is a long vowel (aroma, [ə.ˈɹo͡ʊ.mə]), or it is closed by a coda consonant (objective, [əb.ˈʤɛk.tɨv]), the word will nearly always take stress on that heavy penultimate syllable. (Libermann & Prince, 1977; Halle & Vergnaud, 1982; Hayes, 1982; Olejarczuk & Kapatsinski, 2018; Domahs et al., 2014; Moore-Cantwell, 2020). On the other hand, when the penultimate syllable is light (as in cinnamon [ˈsɪ.nə.mɨn], or banana [bə.ˈnæ.nə]), stress can come on either the penultimate or antepenultimate syllable. Among these light-penult words, final vowel matters: Words whose final vowel is [i] tend to take antepenultimate stress more often than words with other final vowels, the most common being schwa. The effect of final vowel is somewhat weaker than the syllable weight effect, but it still affects speakers' processing and production of nonwords (Moore-Cantwell & Sanders, 2018; Moore-Cantwell, 2020).

In accordance with Schild et al. (2014a, b), Colombo and Sulpizio (2015), Shaw (2012), and Protopapas et al. (2016), we expect to find that speakers choose stress patterns for novel words in accordance with the statistics in the lexicon. We focus on three-syllable words, where we expect more penultimate stress when the penultimate syllable is heavy, and (slightly) more antepenultimate stress when the final vowel is [i].

The main goal of this study is to look for stress priming in the production of novel words when no segmental material overlaps. If so, then this constitutes additional evidence that stress is represented by speakers independently of segmental information. We predict that even when no segmental information overlaps, speakers will produce more antepenultimate stress following an antepenultimately stressed item than following a penultimately stressed item, and conversely, they will produce more penultimate stress following a penultimately stressed item than following an antepenultimately stressed one.

2. Methods

Our goal was to present novel English-like words to our participants, without assigning any stress pattern, so that participants would have to choose a stress pattern themselves. In previous studies, this goal has been achieved by presenting nonwords orthographically and asking participants to say the words out loud. English orthography, however, presents a particular challenge in this case because it does not reliably distinguish between long and short vowels and, therefore, cannot be used to fully specify whether a syllable is heavy or light. We adopt the methodology of Guion et al. (2003), who used novel words to test English speakers' knowledge of stress regularities in the lexicon. They examined the effect on stress production of syntactic category (nouns vs. verbs) and syllable weight, in two-syllable words. In order to get around the effects of orthography, they presented their novel words auditorily, but with an ambiguous or unspecified stress pattern. Participants heard two syllables separated by a pause and equal in duration, intensity, and other cues to stress. Participants were then instructed to string the syllables together into a single word. When they did this, they would naturally assign a stress pattern, which Guion et al. could then transcribe. Using this methodology, Guion et al. found that English speakers followed statistical tendencies in the lexicon in their stress choices: They tend to stress heavy syllables and are more likely to produce initial stress on two-syllable nouns, and final stress on two-syllable verbs.

In our study, we presented three separated syllables to participants, which they were then instructed to repeat, stringing them together into a single fluent word. Crucially, each syllable had to be equally "stressable," based on its phonetics. We constructed items to have the same vowel in both first and second syllables, as well as acoustics that were as similar as possible, so as to avoid any auditory percept of stress in the stimulus. In this way, participants could be given a novel word with unambiguous segmental material, but with no assigned stress pattern, and choose a stress pattern themselves. We expected participants to choose either penultimate stress or antepenultimate stress, which is also initial stress in our items, since all were three syllables long. Henceforth, we will use the label "initial" in this paper for clarity.

2.1. Participants

The participants consisted of 38 University of California, Los Angeles (UCLA) undergraduates who participated in the UCLA Psychology Department Subject Pool (SONA) and received course credit. Language background was assessed with a questionnaire asking participants what languages they speak, and for each language, (a) at what age they began to speak the language, (b) how often they use the language now (a drop down menu, with options: "Every day"; "A few times a week"; "Once a week"; "Once a month"; and "Almost never"), and (c) how well they speak the language now (3-point scale, "Extremely fluent"; "Not bad"; and "Only very simple conversations"). One participant was excluded who reported learning English over the age of 5. The remaining participants were categorized as Monolingual if they listed only English as learned before age 5, and they rated their fluency as “Extremely fluent.” Participants were categorized as Bilingual if they listed English and at least one other language as learned before age 5, and they reported that they spoke that other language every day or a few times a week, OR if they rated their fluency as “Extremely fluent” or “Not bad.” Participants who reported learning a language in addition to English before the age of 5, but who rated their fluency as “Only very simple conversations,” AND reported that they used the language once a week or less, were categorized as Early-exposure. Finally, L2, a category we created for participants who reported a language besides English that they spoke a few times a week or more, and who rated their fluency as “Not bad” or “Extremely fluent,” did not have any participants. The 38 participants fell into the following categories: 25 were Monolingual, 11 Bilingual, and the languages were as follows: Spanish (4), Spanish + Italian (1), Korean (2), Vietnamese (1), Hebrew (1), Armenian (1), Hindi (1), and Farsi (1); and 1 Early-exposure (Spanish). Age and gender information was not collected, though all participants were 18 years old or older.

2.2. Materials

Items consisted of three-syllable long nonce words, which were presented auditorily. Following the methodology from Guion et al. (2003), each item was presented as three syllables separated with short pauses. The first two syllables always contained the same vowel, and the final syllable contained either [i] or [ə]. Items were counterbalanced across participants, appearing with each final vowel, with and without a coda consonant in the penultimate syllable. An example of an item in all four conditions is given in **Table 1**.

Table 1: Example nonce word ti.spli-.m- in four conditions. Each participant heard and produced one version of each item.

	Final vowel [ə]	**Final vowel [i]**
Light penult	[ti] [spli] [mə]	[ti] [spli] [mi]
Heavy penult	[ti] [splif] [mə]	[ti] [splif] [mi]

Four lists were constructed so that each item appeared in every condition across participants, and each individual participant heard an equal number of trials of each of the four conditions, but did not hear the same item twice. Items followed English phonotactic rules but were not similar to any real English words. In particular, we ensured they had no phonological neighbors—real words of English that are just one sound different from the nonword (Vitevitch & Luce, 1999). The number of items constructed was 320, so that each participant heard and produced 80 items in each condition.

To construct the items, a list was made of each unique syllable in the set of stimuli, transcribed into IPA. For example, the syllables [ti], [spli], [splif], [mi] and [mə] were required to create the item shown in **Table 1**. Each unique syllable was pronounced five times by a native speaker of American English (the first author), who attempted to pronounce each with roughly similar duration and pitch contour: a high pitch peak (H* in the ToBI framework, Beckman et al., 2006), followed by a final low pitch (L-L% boundary tone in the ToBI framework). From each set of five, the recording was chosen which was closest to the mean of the entire set on four acoustic measures: duration, intensity, mean pitch and pitch excursion (highest pitch – lowest pitch). In this way we created a set of syllables which were very similar to each other on all these measures. These individual syllable recordings were then spliced together to create the stimuli. For example, the syllable [ti] recording was used to create the item shown in **Table 1**, but also items [bʊ] [pʊ] [ti], [mi] [ti] [kə], and many others. The final set of syllables had an average duration of 832 ms (sd 5.4 ms), an average mean intensity of 72.1 dB (sd 3.9), an average mean pitch across the syllable of 224.8 Hz (sd 9.1), and an average pitch excursion of 103.6 Hz (sd 24.3 Hz).

2.3. Procedure

The experiment was conducted online, using the PCIbex platform (Zehr & Schwartz, 2018). After completing a consent form and language questionnaire, participants took an audio test. They were instructed to take the study in a quiet room, using headphones and a good microphone. To test whether they could produce recordings with clear stress and coda consonants, participants recorded themselves saying the words "cannery," "canary," "critic," and "cryptic," as well as "moss," "moth," "hot," and "hopped." They were then presented with one member of each minimal pair and asked to choose what they heard.[1] If they got more than one pair wrong, they were instructed to try again with a clearer sound setup before proceeding with the study.

Participants were instructed that they would say the names of small towns in the United States, and that they would hear fragments of the name, which they should string together and say fluently, as a single word. We chose to present nonwords as place names inside the United States, to avoid pronunciations influenced by hyperforeignization (Janda et al., 1994). Participants were first given the examples of place names "Alaska" and "Canada," which were presented as individual syllables: [æ][læ][skʌ] and [kæ][næ][dʌ]. These were chosen to illustrate how to string the presented syllables together to make a real word. One initially stressed word (Canada) was chosen, and one penultimate (Alaska), so as not to bias participants toward one stress pattern or the other. Next, they were given the sample nonwords [rɛ][væ][bi] and [zu][rɑf][tʌ]. After each, they were instructed to try it out for themselves, then given example pronounciations [ˈrɛvəbi], [rəˈvæbi], [ˈzurəftə], and [zəˈrɑftə]. They were then given two examples of incorrect

[1] Participants were not generally able to listen to their own recordings later in the study. This was only possible for the audio test.

pronunciations, with the syllables spoken as separate prosodic words instead of a single prosodic word and were told, “Make sure you say the words fluently. Try to avoid answers like these.”

In the experiment proper, each trial began with an auditory presentation of the three-syllable stimulus while the screen displayed a map of the United States with a randomly located star marking the town’s supposed location. When the stimulus was finished, the word “Recording” appeared in red on the screen and recording began. Participants had five seconds to pronounce the word; if they finished in fewer than five seconds, they could press a key and proceed to the next trial. After each trial, a screen appeared instructing participants to press “Enter” and continue. The Enter screen did not have a time limit, so participants could take breaks at any time throughout the experiment. Participants took approximately an hour to complete the entire 320 items.

2.4. Analysis

Seven participants were excluded from analysis either because of recording errors or because they consistently failed to pronounce the nonwords fluently. Recordings from the remaining 30 participants were analyzed to determine participants’ chosen stress patterns on each trial.

2.4.1. Transcribing stress

Recordings were transcribed by a group of ten fluent speakers of American English, including the authors.[2] Each recording was transcribed independently by two transcribers. Stress was transcribed by ear and through visual inspection of the spectrogram in Praat. Transcribers were trained to base their stress judgments on intensity, duration, and pitch alignment. Initial stress was chosen when there was a clear pitch peak on the first syllable, and that syllable had equal or greater intensity and duration compared to the penultimate syllable. Penultimate stress was chosen when there was a pitch rise, or clear plateau in the second syllable, and the penultimate syllable had equal or greater duration compared to the first syllable.

While vowel reduction is generally a good cue to stress in English, it was of limited use here, since participants often did not reduce the vowels of the syllables which they did not stress. We believe this was a result of participants not wanting to stray too far from the phonetics of the prompts, which they were, after all, instructed to repeat. Phonologically, this behavior can be interpreted as secondary stress on syllables which did not get main stress.

Transcribers marked a trial as an error when a recording had poor sound quality or was cut off, when the speaker produced incorrect consonants, out of order consonants, or disfluencies, or when more than one syllable had primary stress. Out of 9600 trials, 459 (4.7%) were marked as errors by both transcribers. An additional 1205 (12.5%) trials were marked as an error by

[2] The remaining transcribers were research assistants in the UCLA Phonology Lab.

one transcriber while the other transcriber marked a stress. These generally reflected different judgment calls about whether a trial had more than one primary stress or not, as it can be difficult to distinguish phonetically from a primary stress and a strong secondary stress. For these trials, we used the stress that was transcribed for analysis. Finally, in 286 transcriptions (3%), transcribers marked different stress patterns. These, and cases where both transcribers marked an error, were excluded from analysis.

2.4.2. Acoustic analysis of stress

Acoustic measures of stress were congruent with our transcriptions but did not provide a better method of categorizing stress. Duration, intensity, and pitch-excursion measures broadly aligned with our transcriptions, but often indicated different stress patterns for individual utterances. We also examined vowel quality, finding that in line with previous literature, the vowels marked as stressed had more extreme formant values than those marked as stressless. Finally, we measured the duration of silence on each recording before the participant began speaking. This latency was affected by stress priming in Shaw (2012, 2013), but we did not find any effect of latency in the current study, so this measure will not be discussed further.

We used the Montreal Forced Aligner (McAuliffe et al., 2017), with the pre-trained model english_us_arpa, to segment each recording according to the transcribed stress pattern. For each vowel, we used Praat (Boersma & Weenink, 2023) to measure its duration, intensity, pitch, and vowel formants.

Stress in English is strongly correlated with vowel quality, duration, intensity, and pitch. Fry (1958) found that stressed syllables were longer and louder than unstressed ones, and had a larger pitch range. This basic result has been confirmed by many subsequent studies, reviewed in Plag et al. (2011; see especially Beckman, 1986; Fear et al., 1995; Hayes, 1995; and Lindblom, 1963). The effect of pitch in particular is difficult to disentangle from the effect of intonational contours. Plag et al. examined the acoustics of word stress in both accented and unaccented contexts, and found that all acoustic cues to stress were weaker in unaccented contexts, especially pitch, but all were still statistically significant. The utterances in this study are single-word, which we expect to behave like an accented position. This means that pitch and all other acoustic differences between stressed and unstressed positions should be relatively strong. We calculated ratios of first to second syllable duration, intensity, and pitch excursion (highest pitch – lowest pitch). A ratio greater than 1 for any of these would mean that the first syllable of the utterance was stronger on that measure than the second, pointing to Initial stress. A ratio of less than 1 would mean the opposite: that the second syllable was stronger on that measure, pointing to Penultimate stress. **Figure 1** plots these ratios and their relationship to each other in the participants' utterances. Each ratio is log-transformed so that it is more or less normally distributed. A log of 1 is zero, so in the graphs, any value above zero indicates Initial stress, and any value below zero indicates Penultimate stress. These measurements would be most useful in determining participants' intended stress pattern if (a) one or more measures were clearly bimodal in distribution, or (b) two or more measures could be used together to categorize the utterance's stress. In **Figure 1**, it is easy to see that all measures are basically unimodal, and that any two measures have a high disagreement rate, indicated by light grey dots in the graph. The light grey dots are utterances where by one measure the utterance should count as Penultimate stress, while by the other measure it should count as Initial stress. In the best aligned pair—duration and pitch excursion—nearly one-third (31%) of utterances are ambiguous in this way.

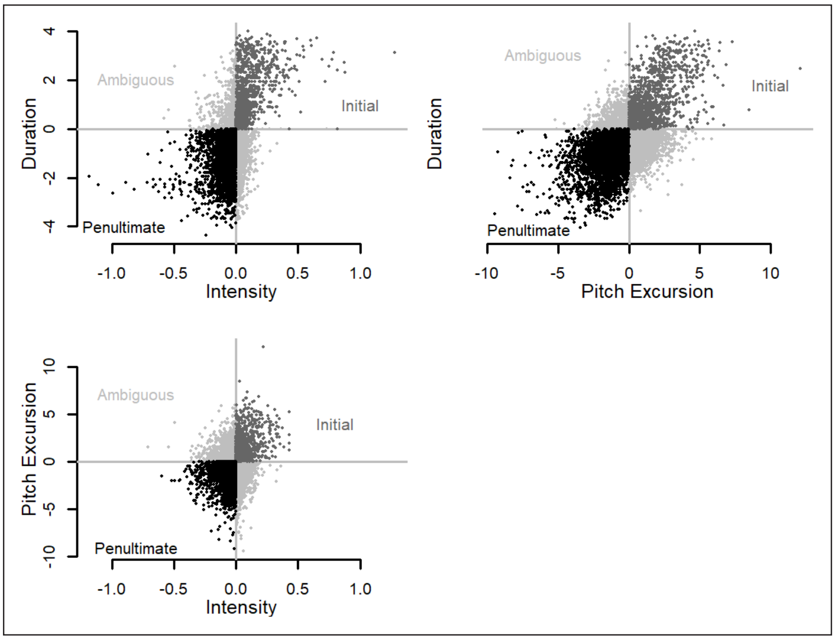

Figure 1: Acoustic measurements of stress in participants' utterances. All measures are log-transformed ratios of first to second syllable measurements. When both measures in a graph agree that the utterance most likely has Penultimate stress, the utterance is plotted in black. When both measures agree that the utterance most likely has Initial stress, the utterance is plotted in dark grey. Light grey dots are utterances where the two measures disagree.

Though our pitch, duration, and intensity measures do not perfectly predict the stress patterns that transcribers heard, they do correlate. Utterances transcribed by both transcribers with initial stress had a mean log duration ratio of 0.68, a mean log intensity ratio of 0.03, and a mean pitch excursion ratio of 0.26. Those transcribed with penultimate stress had a mean log duration ratio of –0.94, a mean log intensity ratio of –0.04, and a mean pitch excursion ratio of –0.50. Utterances where the two transcribers disagreed fell in the middle on every measure, with a mean log duration ratio of 0.12, a mean log intensity ratio of 0.01, and a mean pitch excursion ratio of 0.25. This last fact suggests that transcribers disagreed in cases where the acoustics were ambiguous.

Finally, although vowel quality did not vary much between stressed and stressless syllables, formant measurements over the whole experiment show that vowels transcribed as stressless were often slightly reduced compared to those transcribed as stressed, though the amount of reduction varied by vowel. **Figure 2** illustrates formant values for stressed vowels in dark grey and unstressed vowels in light grey. Low and mid vowels transcribed as unstressed had overall more central and mid realizations than those same vowels when transcribed as stressed. High vowels were not different when stressed vs. unstressed, however.

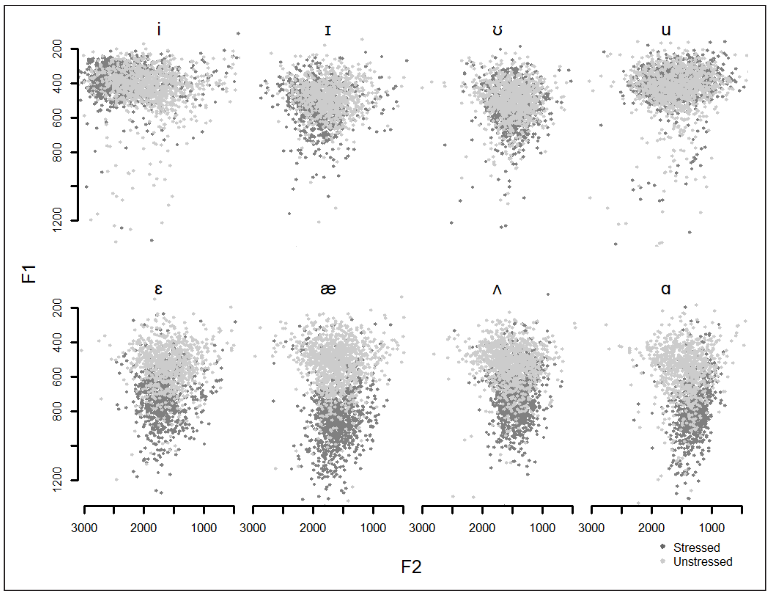

Figure 2: First and second formant values for each vowel that appeared in the study. Dark grey dots are utterances where the vowel was transcribed as stressed, while light grey dots were transcribed as unstressed.

2.4.3. Transcription of codas

Penultimate syllable codas were also transcribed, as in many cases the participant produced a coda that did not match the coda consonant given in the stimulus or failed to produce a coda at all. Penultimate syllable codas were counted as a disagreement only if transcribers disagreed about whether there was a coda or not. If both transcribers noted a coda, but they marked different consonants (often voiced-devoiced pairs, like p/b, t/d, s/z, etc.), the utterance was counted as having a heavy penultimate syllable. Transcribers disagreed on the presence of a coda on 788 trials (8% of total). These trials were excluded from analysis.

2.4.4. Mixed-effects modeling

We fit a mixed-effects logistic regression using glmer() in the lme4 package in R (Bates et al., 2015). Stress transcription was the dichotomous dependent variable, dummy coded with Initial stress as the reference level (compared to Penultimate). All fixed factors were also dichotomous and dummy coded. Reference levels are listed first and bolded for each. Our main variable of interest was last trial stress (**Initial** or Penultimate). Last trial stress interacted with stressed vowel match (**Mismatch** or Match) and with final vowel match (**Mismatch** or Match). The weight of the penultimate syllable (**Light** or Heavy) and final vowel (**ə** or i) were included, along with their interaction. Finally, interactions were fit between last trial stress and last trial penult weight (**Light** or Heavy), and between last trial stress and last trial final vowel (**ə** or i). To account for any item-specific effects, random intercepts were included for items; to account for individual participants' behavior, in particular participants' specific preferences for one stress pattern over the other, we included random intercepts for participants.[3] The random intercepts for participants were particularly important to include since, as discussed below, participants exhibited a wide range of individual stress preferences. **Table 2** shows the full model equation and fitted model coefficients. Positive coefficients indicate more penultimate stress. Because all variables were dummy coded, the intercept should be interpreted as the expected value at the reference levels of all factors, and main effects should be interpreted as the expected value at reference levels of interactions. Importantly, this means that the main effect of last trial stress should be interpreted as the effect of last trial stress in the absence of segmental overlap: when stressed vowels and final vowels mismatch.

3. Results

3.1. Summary of results

The fitted values of our mixed-effects regression model are given in **Table 2**. Overall, penultimate stress was produced more often than initial stress (83% of trials). Last trial stress, our main variable of interest, was a significant predictor: When the previous trial had penultimate stress, participants were more likely to produce penultimate stress again ($\beta = 0.46$, $p < 0.001$). This main effect can be interpreted as the effect of last trial stress specifically when no segmental material overlapped, since the reference level for both segmental match conditions was Mismatch. Stressed vowel match did not affect stress placement ($p > 0.1$), but somewhat surprisingly when a trial's final vowel matched the final vowel of the previous trial, participants produced more initial stress ($\beta = -0.37$, $p = 0.02$). As expected, last trial stress interacted with the two segmental match conditions. When the stressed vowel matched ($\beta = 0.57$, $p = 0.047$), or the final vowel matched ($\beta = 0.39$, $p = 0.03$), the effect of a previous penultimate stress was stronger. Lexical effects were also found for a trial's penultimate weight ($\beta = 2.63$, $p < 0.001$) and final vowel ($\beta = -0.30$, $p < 0.001$). These did not interact with each other and did not interact with previous item effects.

[3] We also tried to fit a full model including random slopes, but this model did not converge.

Table 2: Summary of a mixed-effects logistic regression, stress transcription as the dependent variable.

Equation: Stress transcription ~ Penult W * Final V + prevStress* prevW + prevStress * prevV + prevStress * stressVmatch + prevStress * finalVmatch + (1|participant) + (1|item)			
	Estimate	**Z**	**p**
Intercept:	1.38	3.780	*<.001*
Previous Item effects:			
Previous penult stress	*0.46*	*2.61*	*0.009*
Previous heavy penult	–0.24	–1.32	0.19
Previous final i	0.18	1.17	0.25
Previous stressed vowel match	–0.29	–1.25	0.21
Previous final vowel match	*–0.37*	*–2.40*	*0.02*
Previous Item interactions:			
Prev. penult stress × Prev. heavy penult	–0.01	–0.06	0.95
Prev. penult stress × Prev. final i	–0.17	–0.94	0.35
Prev. penult stress × Prev. stressed v. match	*0.57*	*1.98*	*0.047*
Prev. penult stress × Prev. final v. match	*0.39*	*2.15*	*0.03*
Lexical effects:			
Heavy penult	*2.63*	*18.42*	*<.001*
Final i	*–0.30*	*-3.22*	*0.001*
Heavy penult × Final i	0.14	0.75	0.45

3.2. Stress priming in production

Figure 3 illustrates the effect of last trial stress found in our regression. Bar widths correspond to group size. Because penultimate stress was produced much more than initial stress overall, trials preceded by penultimate stress are far more numerous than trials preceded by initial stress. Bars are divided vertically based on the percentage of trials in each group with initial stress (the dark bars) or penultimate stress (the light bars). When penultimate stress preceded, more penultimate stress was given, while when initial stress preceded, more initial stress was given. The absolute difference in rate of initial stress after initial minus the rate of initial after penultimate was 0.29 (29%).

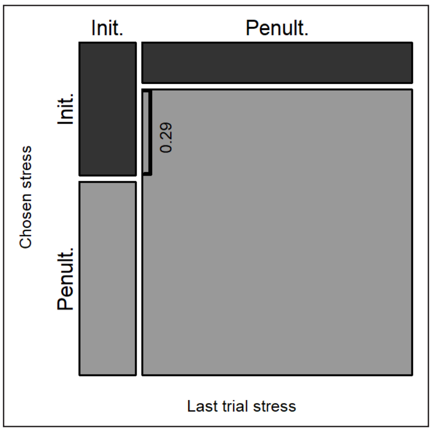

Figure 3: Priming from trial to trial. Participants produced 29% more initial stress after a preceding trial where they had just produced initial stress. Vertical bars indicate percentages. Bar widths correspond to group size.

3.3. Individual participants' behavior

Participants differed in their overall rate of initial stress in the experiment. This was modeled in our regression using random intercepts for participants. In **Figure 4** we compare each participant's overall rate of initial stress (x-axis) to their rate of initial stress when the previous trial was initial (y-axis). If the y-axis value exceeds the x-axis value, then that participant exhibited a priming effect, and the size of that priming effect is the distance between the point and the x = y line. This distance indicates the percentage of that participant's initial stress productions, which cannot be accounted

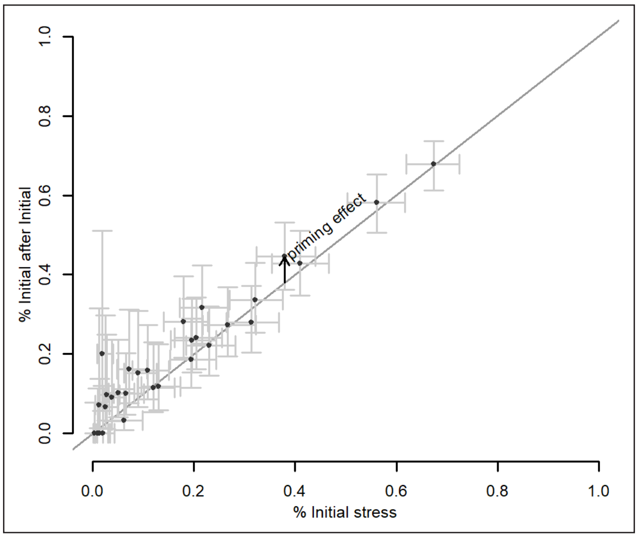

Figure 4: Rate of initial stress produced by each participant overall (x-axis) vs. after another initial stress (y-axis). Confidence intervals are included for both measurements: Wilson 95% intervals, shown in grey bars. Any participant above the y = x line exhibited a priming effect for initial stress, and the size of that priming effect is the distance of the point away from the x = y line.

for by their overall rate of initial stress. Error bars are also included for both percentages, using 95% Wilson confidence intervals. Not all participants exhibit a priming effect, but a majority do.

3.4. Effects of segmental overlap

Figures 5 and **6** illustrate the interactions in our regression between last trial stress and stressed vowel match, and between last trial stress and final vowel match. When stressed vowels matched, the effect of last trial stress was stronger by 0.09 (9%). When final vowels matched, the effect of last trial stress was stronger by just 0.02 (2%).

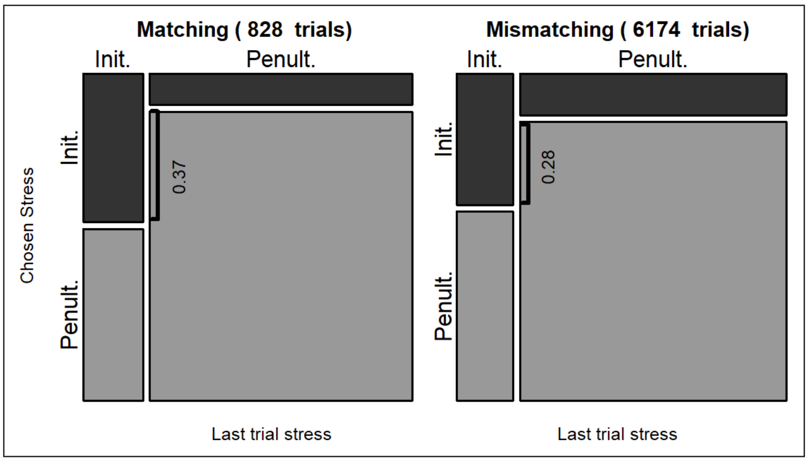

Figure 5: Effects of stressed vowel matching on the size of the stress priming effect. The effect is 0.09 (9%) larger when prime and target matched stressed vowels.

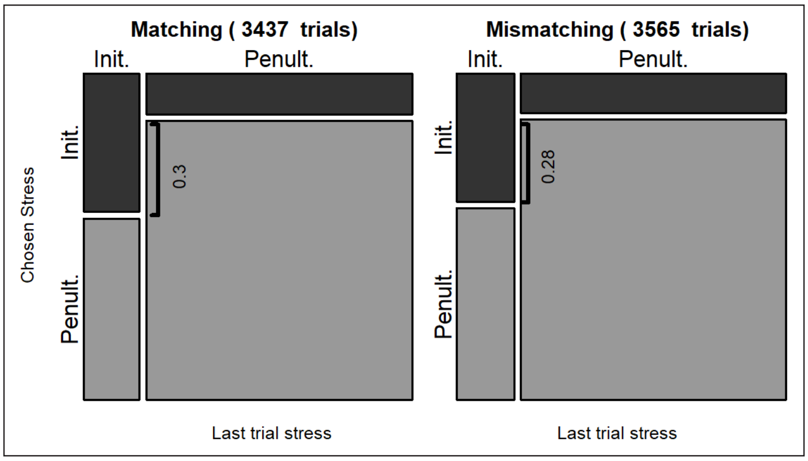

Figure 6: Effects of final vowel (i, or ə) matching on the size of the stress priming effect. The effect is 0.02 (2%) larger when prime and target matched final vowels.

4. Discussion

Our results support the Abstract Representation Hypothesis. Participants' recently-produced stress patterns affected their choices of stress on novel words, even in the absence of segmental match. This finding contrasts with much of the previous literature on the effects of stress priming in lexical decision tasks, where effects are typically only found when stress and segmental material overlap (for example, Protopapas et al., 2016). However, studies using measurements other than reaction time typically do find effects of stress match in the absence of segmental match. ERP components are affected by stress match, and most related to our findings: Production studies such as Colombo and Zevin (2009) and Shaw (2012, 2013) find greater numbers of stress errors in production when a word is preceded by a mismatching stress. We hypothesized that stress may behave like syntactic structure in priming: It may be easier to observe in structure choices than in reaction times (Pickering & Ferreira, 2008). Unlike syntactic structure, which speakers must choose regularly while speaking, stress patterns are typically either completely determined by the language's grammar, or, as in English, dictated by each word's lexical entry. To allow participants to make a choice of stress pattern, we used nonwords whose stress pattern was not known by participants in advance. With this methodology, we observed stress priming with greater effect size when segments did overlap between prime and target, but which clearly persisted when segments did not overlap. This result indicates that an abstract representation of stress is available to participants to be activated from trial to trial.

We found that the effect of priming from trial to trial was stronger when stressed vowels matched, and when the two trials' final vowels matched. One possible explanation for this is that participants have access to multiple types of stress representation—one with no segmental information affiliated and another that is local to the stressed vowel. Both would be activated on each trial and influenced the following trial. For example, if the first trial were the item [fæ] [ræ] [ni], which the participant produced with initial stress ([ˈfæ.rə.ni]), the metrical frame ˈσσσ would be activated, as would the stressed vowel ˈæ. Only the metrical frame would make initial stress more likely on a following item like [ku] [mup] [si], but both would contribute to making initial stress more likely on a following item like [bæ] [mæ] [kə].

So far, this explanation fails to completely account for our findings. All of our items have the same vowel in the first and second syllable. So, having only a stressed vowel active does not inform which syllable of the word should be stressed. An activated ˈæ could just as easily lead a participant to stress the first or the second æ in [bæ] [mæ] [kə]. Rather, the representation(s) activated from trial to trial must contain stressed vowel information and location information. For example, if the stressed vowel were linked to a particular syllable in the metrical frame, or to a particular syllable location ("second syllable" for example), then its activation could facilitate second syllable stress on the following word.[4] Along these lines, we also find an effect of final

[4] Thanks to an anonymous reviewer for pointing this possibility out.

vowel overlap. Final vowels are never stressed and are non-local to the word's stress. A stressless final i, as in [ˈfæ.rə.ni], without context, would not match initial stress or penultimate stress any differently, and its activation would not lead the participant to prefer one of these over the other in the next trial. The final i must be linked not just to a location (3rd syllable), but also to information about what is happening in other locations in the word ("3rd syllable, and the first syllable is stressed").

One possible model for the complex representations that might be involved in our segmental overlap effects comes from models of the "lexical boost" in syntactic structural priming, where lexical overlap enhances priming of a particular structure (Tooley & Traxler, 2010; Mahowald et al., 2016), doubling or even tripling the effect size (Pickering & Branigan, 1998). Tooley and Traxler, and Mahowald et al., argue that the lexical boost is the result of residual activation on both the combinatorial nodes responsible for the structure in question and the lexical items which could possibly fill that syntactic structure. When structure and lexical items are the same in the prime and the target, residual activation on the structure, the lexical item, and their connection lead to a larger priming effect. A similar explanation could account for the effects we find from segmental overlap in stress priming. Metrical frame, segments and, importantly, their connections, have residual activation from one trial to the next, leading participants to choose primed stress patterns more often when segments overlap in addition to stress, regardless of where the segmental overlap appears in the word.

Our results do not distinguish between two possible types of abstract representations of stress. The metrical frame approach of Levelt et al. (1999) claims that a word's stress pattern is stored as a simple sequence of syllables, with one or more marked as stressed. This frame can then be filled with segmental material later in the word production process. Metrical feet are most commonly used to describe stress typology across multiple languages and the stress grammar of individual languages. These are groupings typically of just two syllables, where one syllable is strong, and the other is weak. Not every syllable in the word must be footed, so trisyllabic words like the ones we used in our study would have a structure like {(ˈfæ.rə)ni} or {fə(ˈræ.ni)} (Moore-Cantwell, 2020). Foot structure like this is a more complex representation than the metrical frame approach but may have some psychological reality in German (Domahs et al., 2008) and Turkish (Domahs et al., 2013). For our results, both types of representation are equally plausible.

A puzzle in our results is the large rate of penultimate stress responses. Many participants gave almost no initial stress responses throughout the whole experiment. This is unexpected based on the lexicon, where initial stress is prevalent in words with light penult syllables and predominant in words with light penultimate syllables and a final [i]. The high rate of penultimate stress we observe is also incongruous with the results found in Moore-Cantwell (2020), in which participants produced between 50% and 70% initial stress on words with a light penultimate syllable. The comparison to Moore-Cantwell (2020) is particularly striking since the methodology in those studies is extremely similar to the methodology presented here. Moore-Cantwell used fewer items than the present study (just 32), did not include the United States map which we visually presented during the task, and included a two-alternative forced choice task, where participants heard two versions of the nonword's stress and chose between them. Our increased number of items may have led to adaptation over the course of the study, or participants may have become tired and behaved differently near the end of the study.

To check whether the number of trials mattered, we examined just the first 32 trials of our study to see if they more closely resembled Moore-Cantwell's 2020 results. The overall rate of penultimate stress in our study was 83%. In the first 32 trials only, it was 77%, — a lower rate, but nowhere near the approximately 50% observed in Moore-Cantwell (2020). We believe a better explanation of our high rate of penultimate stress is the presence of the United States map. While we intended this map to encourage participants to treat the nonwords as native English words, it may have had the opposite effect. Dabouis and Fournier (2022) argue that many place names in English, especially in the United States, follow the statistical patterns of foreign words rather than core English vocabulary. Furthermore, foreign vocabulary tends to have primarily penultimate stress.

Our results also have implications for interpreting the results of production tasks involving nonwords. Studies with a structure similar to ours are frequently used within generative phonology (Chomsky & Halle, 1968). Speakers are theorized to have complex, structured, and abstract knowledge of the sound system of their native language, in the form of rules or constraints (Prince & Smolensky 1993/2004), generally referred to as speakers' "phonological grammar." Studies like ours, in which participants are given some information about a novel word and must fill in the rest, are often interpreted as directly revealing aspects of the phonological grammar that participants use. Because speakers behave probabilistically on these tasks, producing outcomes proportional to their occurrence in the lexicon, a strain of more recent research views the grammar as gradient and probabilistic in nature (Boersma & Hayes, 2001; Garcia, 2017; Goldwater & Johnson, 2003; Hayes et al., 2009; Zuraw, 2000; and many others). Our results show that more factors than phonological grammar influence participants' decisions on novel words. Our priming effect would not cause a categorical grammatical rule to appear as a probabilistic tendency (Dillon & Wagers, 2021; Durvasula & Gorman, in preparation), since if a structure were disallowed altogether, participants would never produce it for it to then become a prime for a subsequent trial. However, our results do indicate that observed production probabilities of a certain structure should not be interpreted as a straightforward reflection of the phonological grammar. If priming effects such as ours can be boosted or dampened by making the task harder or easier, or by using different presentation modality, we would expect to see more low-probability forms when priming is strong, and fewer when priming is weak.

5. Conclusion

In this paper we report a production-to-production priming effect of stress in a novel word production task. When participants must choose a stress pattern for a novel word, their choices are influenced both by statistical tendencies in their language and by recent stress patterns they have produced. This paradigm has much in common with typical production priming studies of syntactic structures (Bock, 1986), and builds on previous production studies which find stress priming effects in participants' production errors. Although previous studies which examined the lexical access process found priming effects of stress only when segmental material overlapped between prime and target, our priming effect was robust even when no segments matched. Consistent with previous literature, however, we found that our priming effect was boosted when any segments overlapped: Overlap mattered both for the stressed vowel and for the final vowel which was never stressed. Our results align with the hypothesis that both segments and abstract stress representations are active during production.

Appendix: Items

syll 1	syll 2	syll 3	syll 1	syll 2	syll 3	syll 1	syll 2	syll 3
fæ	ɹæ(k)	ni/ʌ	zi	mi(s)	ɹi/ʌ	ʔu	zu(v)	di/ʌ
pʌ	tʌ(k)	ʤi/ʌ	bæ	θæ(k)	ti/ʌ	ʔɑ	dɑ(v)	ni/ʌ
lu	ɹu(p)	ti/ʌ	ʧi	ɹi(k)	si/ʌ	θɑ	mɑ(g)	di/ʌ
fu	ʒu(p)	gi/ʌ	ʧʊ	lʊ(g)	bi/ʌ	du	ɹu(k)	ʤi/ʌ
pu	mu(k)	ti/ʌ	fʊ	zʊ(k)	mi/ʌ	θɪ	kɪ(p)	si/ʌ
θi	ɹi(d)	zi/ʌ	ʤæ	mæ(g)	di/ʌ	sɪ	gɪ(k)	θi/ʌ
tu	ʤu(f)	ti/ʌ	pɛ	kɛ(d)	bi/ʌ	vʌ	kʌ(b)	di/ʌ
ni	di(v)	gi/ʌ	gi	fi(t)	si/ʌ	zʊ	mʊ(f)	ki/ʌ
tɹʌ	wʌ(f)	gi/ʌ	lɛ	fɛ(s)	pi/ʌ	du	pu(d)	zi/ʌ
dɹɛ	kɛ(d)	li/ʌ	nu	su(k)	ti/ʌ	tæ	sæ(d)	ki/ʌ
tɹæ	gæ(p)	ni/ʌ	nʊ	kʊ(p)	ti/ʌ	gʌ	vʌ(f)	si/ʌ
blʌ	zʌ(f)	ki/ʌ	ʤʌ	kʌ(f)	mi/ʌ	kæ	fæ(d)	li/ʌ
ni	ʒi(d)	ki/ʌ	ɹʌ	sʌ(v)	di/ʌ	vɪ	ðɪ(k)	ni/ʌ
sɑ	fɑ(b)	si/ʌ	ʤɛ	sɛ(k)	ti/ʌ	gɪ	ɹɪ(b)	zi/ʌ
ʃʊ	kʊ(d)	fi/ʌ	gʌ	ʃʌ(b)	zi/ʌ	lɑ	ɹɑ(b)	ʃi/ʌ
zi	li(p)	ki/ʌ	nɛ	jɛ(v)	zi/ʌ	fɑ	lɑ(f)	di/ʌ
ʧu	kɹu(p)	ti/ʌ	nɛ	θɛ(g)	ɹi/ʌ	θu	ku(k)	ti/ʌ
wu	glu(b)	zi/ʌ	fɑ	ɹɑ(d)	zi/ʌ	ɹʊ	zʊ(v)	li/ʌ
ʧʌ	bɹʌ(p)	fi/ʌ	kɑ	ɹɑ(f)	ʤi/ʌ	gʌ	bʌ(k)	ti/ʌ
ti	spli(f)	mi/ʌ	wʊ	nʊ(z)	ɹi/ʌ	nɑ	ðɑ(g)	ki/ʌ
wu	mu(d)	ni/ʌ	sɛ	pɛ(g)	di/ʌ	kɹɪ	lɪ(d)	mi/ʌ
du	gu(p)	si/ʌ	wi	ɹi(k)	ʤi/ʌ	lʌ	gʌ(f)	bi/ʌ
zɑ	ðɑ(p)	mi/ʌ	ʧi	zi(p)	ki/ʌ	bɹɛ	glɛ(g)	zi/ʌ
gɪ	plɪ(d)	ni/ʌ	næ	ɹæ(k)	ti/ʌ	skʊ	blʊ(p)	ti/ʌ
mi	ʒi(f)	ki/ʌ	mu	ʤu(f)	ti/ʌ	snɑ	pɑ(k)	ti/ʌ
tɪ	jɪ(k)	si/ʌ	ɹi	kli(b)	di/ʌ	gɹu	fu(d)	smi/ʌ
gu	lu(p)	fi/ʌ	wɛ	dɹɛ(k)	θi/ʌ	ɹæ	ðæ(k)	pi/ʌ
θɪ	ʃɪ(d)	li/ʌ	lu	ʧɹu(f)	ti/ʌ	dʌ	ɹʌ(d)	zi/ʌ
nu	su(p)	gi/ʌ	lɑ	kɹɑ(f)	ti/ʌ	ku	θu(f)	ti/ʌ
di	ʒi(k)	fi/ʌ	ʃɑ	nɑ(f)	ti/ʌ	di	li(k)	mi/ʌ
ʧæ	mæ(s)	ɹi/ʌ	bi	ði(d)	fi/ʌ	pʊ	bʊ(g)	ʃi/ʌ

(Contd.)

syll 1	syll 2	syll 3	syll 1	syll 2	syll 3	syll 1	syll 2	syll 3
væ	ɹæ(p)	si/ʌ	sæ	ʧæ(z)	di/ʌ	pɛ	fɛ(d)	vi/ʌ
dɹu	vu(p)	si/ʌ	li	pi(g)	zi/ʌ	ði	mi(f)	ti/ʌ
ski	ni(f)	ʤi/ʌ	pɹɛ	pɛ(g)	di/ʌ	ɹɪ	gɪ(k)	pi/ʌ
gɹʊ	bʊ(v)	zi/ʌ	klɛ	ʧɛ(z)	mi/ʌ	θɑ	ɹɑ(g)	mi/ʌ
stu	pu(f)	ki/ʌ	kɹɪ	ʧɪ(f)	ki/ʌ	θæ	kæ(g)	di/ʌ
bʊ	pʊ(k)	ti/ʌ	stʌ	plʌ(θ)	ɹi/ʌ	bu	ɹu(k)	ti/ʌ
pʊ	dʊ(f)	bi/ʌ	sti	ʧi(d)	ki/ʌ	zʌ	kʌ(g)	mi/ʌ
wɪ	θɪ(b)	zi/ʌ	smʌ	gʌ(f)	ti/ʌ	ʧɪ	lɪ(d)	zi/ʌ
væ	tæ(g)	zi/ʌ	dɹʊ	θʊ(d)	zi/ʌ	ʧi	fi(p)	ti/ʌ
ʔɛ	pɛ(f)	si/ʌ	spɑ	nɑ(d)	mi/ʌ	jæ	ɹæ(k)	ti/ʌ
ʔɑ	ʤɑ(d)	ni/ʌ	mɛ	gɹɛ(p)	ti/ʌ	nɪ	lɪ(s)	ɹi/ʌ
ʔɑ	θɑ(z)	vi/ʌ	dæ	kjæ(b)	zi/ʌ	ʔʊ	vʊ(d)	zi/ʌ
ʔʊ	ɹʊ(k)	ʧi/ʌ	dʊ	ʧɹʊ(k)	fi/ʌ	ʔi	ʤi(b)	mi/ʌ
sæ	kæ(d)	ʃi/ʌ	fɛ	skɛ(d)	pi/ʌ	ʔɪ	lɪ(d)	gi/ʌ
gi	di(p)	si/ʌ	gu	mu(k)	ʧi/ʌ	ʔu	zu(k)	ti/ʌ
plɛ	ɹɛ(f)	bi/ʌ	ʧʌ	dʌ(v)	zi/ʌ	tʊ	vʊ(g)	ni/ʌ
kɪ	ɹɪ(k)	θi/ʌ	ɹæ	fæ(d)	zi/ʌ	bɪ	gɪ(d)	zi/ʌ
pʊ	ʃʊ(v)	ɹi/ʌ	kæ	zæ(b)	ki/ʌ	θʊ	ɹʊ(v)	di/ʌ
sɪ	mɪ(p)	si/ʌ	ʤɑ	bɑ(k)	fi/ʌ	mi	gi(k)	ti/ʌ
fɛ	sɛ(b)	di/ʌ	θʊ	fʊ(g)	zi/ʌ	pi	bɹi(d)	zi/ʌ
bu	mu(f)	gi/ʌ	ɹʊ	pʊ(b)	zi/ʌ	sæ	ðæ(t)	ki/ʌ
ʔu	ɹu(k)	si/ʌ	tʊ	mʊ(p)	si/ʌ	dʌ	mʌ(f)	zi/ʌ
ʔʊ	ʧʊ(d)	vi/ʌ	ɹu	nu(k)	li/ʌ	ni	zi(s)	ɹi/ʌ
ʔʊ	mʊ(v)	zi/ʌ	su	mu(p)	si/ʌ	θʌ	bɹʌ(k)	si/ʌ
ʔʊ	kʊ(v)	ɹi/ʌ	ku	ku(p)	ti/ʌ	di	ɹi(k)	si/ʌ
wi	mi(g)	zi/ʌ	bʌ	lʌ(p)	ti/ʌ	gɛ	lɛ(g)	bi/ʌ
nɑ	bɑ(k)	ʤi/ʌ	gæ	pæ(k)	ti/ʌ	fʊ	gʊ(k)	mi/ʌ
θɛ	vɛ(p)	si/ʌ	ɹɑ	lɑ(d)	ki/ʌ	mʌ	kʌ(g)	di/ʌ
si	ɹi(k)	θi/ʌ	lʌ	ʤʌ(f)	si/ʌ	ku	lu(z)	gi/ʌ
vɪ	pɪ(b)	di/ʌ	lʌ	ɹʌ(v)	gi/ʌ	fɑ	ʤɑ(k)	si/ʌ
zʌ	ʤʌ(f)	ki/ʌ	spæ	θæ(f)	si/ʌ	kæ	ɹæ(k)	si/ʌ
pʌ	θʌ(d)	zi/ʌ	dɹʊ	lʊ(d)	bi/ʌ	nɛ	kɛ(k)	ti/ʌ

(Contd.)

syll 1	syll 2	syll 3	syll 1	syll 2	syll 3	syll 1	syll 2	syll 3
pɪ	θɪ(d)	ki/ʌ	klɛ	fɛ(p)	mi/ʌ	lɑ	gɑ(p)	ti/ʌ
gʌ	tʌ(f)	si/ʌ	bli	mi(s)	fi/ʌ	mɪ	ɹɪ(f)	mi/ʌ
pɛ	vɛ(d)	pi/ʌ	nʌ	ðʌ(d)	fi/ʌ	zɪ	fɪ(v)	di/ʌ
vu	zu(k)	ni/ʌ	ʤʊ	sʊ(k)	fi/ʌ	ʤæ	gæ(k)	ti/ʌ
ti	ði(b)	zi/ʌ	ʃɪ	bɹɪ(d)	fi/ʌ	ʃʌ	ɹʌ(b)	zi/ʌ
mæ	θæ(b)	ʃi/ʌ	zɪ	θɪ(p)	fi/ʌ	jɪ	mɪ(v)	zi/ʌ
si	ʤi(f)	di/ʌ	kɛ	bɛ(p)	ti/ʌ	θɪ	gɪ(g)	ni/ʌ
θæ	tæ(p)	si/ʌ	ɹi	fɹi(b)	zi/ʌ	kæ	dæ(d)	zi/ʌ
lu	lu(v)	ɹi/ʌ	dʌ	bɹʌ(p)	fi/ʌ	kʌ	lʌ(f)	ʤi/ʌ
bʊ	jʊ(k)	ti/ʌ	tʌ	spʌ(f)	ti/ʌ	mʌ	fʌ(z)	ɹi/ʌ
mu	ðu(g)	ni/ʌ	wʌ	mʌ(t)	li/ʌ	ʧʌ	lʌ(g)	di/ʌ
wæ	læ(d)	mi/ʌ	swɛ	lɛ(p)	ti/ʌ	swæ	kæ(k)	ʤi/ʌ
lɪ	nɪ(f)	bi/ʌ	zʌ	ðʌ(p)	ki/ʌ	ɹʊ	zʊ(p)	ki/ʌ
pli	fɹi(g)	zi/ʌ	tæ	bɹæ(d)	mi/ʌ	mʌ	zʌ(k)	ti/ʌ
stɑ	gɹɑ(p)	ti/ʌ	pæ	dæ(f)	ɹi/ʌ	ʤɪ	fɪ(k)	ti/ʌ
smʊ	ɹʊ(k)	ti/ʌ	tʌ	gʌ(k)	si/ʌ	mɪ	bɹɪ(g)	di/ʌ
kɹu	fu(d)	spi/ʌ	tʊ	fʊ(d)	li/ʌ	wʌ	skʌ(v)	bi/ʌ
mu	ɹu(k)	pi/ʌ	θʊ	ʃʊ(d)	bi/ʌ	lɪ	smɪ(f)	ti/ʌ
tæ	θæ(d)	zi/ʌ	tu	su(f)	di/ʌ	ʧɛ	slɛ(f)	ti/ʌ
ɹi	θi(f)	ti/ʌ	du	θu(t)	gi/ʌ	dɑ	lɑ(f)	ti/ʌ
ki	di(k)	ʤi/ʌ	tɑ	zɑ(s)	ɹi/ʌ	bɪ	mɪ(d)	ɹi/ʌ
tʊ	pʊ(g)	ʃi/ʌ	væ	θæ(p)	si/ʌ	kɑ	lɑ(b)	zi/ʌ
fæ	tæ(d)	vi/ʌ	kɹɑ	lɑ(p)	si/ʌ	pɪ	kɪ(g)	zi/ʌ
ðu	nu(f)	si/ʌ	stæ	kæ(f)	ʤi/ʌ	blɛ	fɛ(g)	di/ʌ
wɑ	mɑ(k)	pi/ʌ	tɹʌ	bʌ(t)	zi/ʌ	glɛ	fɛ(k)	ti/ʌ
mi	ti(g)	ki/ʌ	bɹɛ	nɛ(s)	li/ʌ	smɛ	lɛ(f)	ki/ʌ
θɪ	tɪ(g)	pli/ʌ	tæ	pæ(k)	si/ʌ	ʧɹɑ	blɑ(θ)	ɹi/ʌ
vɑ	bɑ(k)	ti/ʌ	gʌ	dʌ(f)	bi/ʌ	smɪ	ɹɪ(d)	ki/ʌ
ɹi	si(g)	mi/ʌ	θɪ	lɪ(b)	zi/ʌ	blʊ	gʊ(f)	ti/ʌ
ʧʌ	wʌ(d)	zi/ʌ	vɛ	kɛ(f)	ʃi/ʌ	slɪ	dɪ(d)	zi/ʌ
nɛ	vɛ(p)	ti/ʌ	ʔɛ	sɛ(f)	ti/ʌ	spɛ	bɛ(s)	ɹi/ʌ
ɹæ	jæ(k)	ti/ʌ	ʔɪ	θɪ(k)	ʧi/ʌ	tʌ	kjʌ(p)	ti/ʌ

(Contd.)

syll 1	syll 2	syll 3	syll 1	syll 2	syll 3	syll 1	syll 2	syll 3
næ	mæ(s)	bi/ʌ	ʔi	pli(z)	ɹi/ʌ	gu	bɹu(b)	zi/ʌ
ʔi	si(p)	θi/ʌ	ʔʊ	ʧʊ(k)	ti/ʌ	dɑ	slɑ(k)	fi/ʌ
ʔu	nu(b)	ʤi/ʌ	lɑ	pɹɑ(d)	zi/ʌ	ɹu	blu(d)	pi/ʌ
ʔɑ	nɑ(d)	li/ʌ	dɛ	ʧɛ(p)	si/ʌ	mæ	fæ(b)	ni/ʌ
ʔu	θu(k)	di/ʌ	ɹʊ	fʊ(f)	ti/ʌ	ʧɑ	ɹɑ(v)	di/ʌ
wæ	væ(g)	ði/ʌ	gu	ɹu(k)	θi/ʌ	fʊ	mʊ(d)	zi/ʌ
vi	bi(d)	zi/ʌ	tɹʌ	dʌ(v)	ɹi/ʌ	mi	sli(b)	ki/ʌ
gi	θi(f)	ti/ʌ	zɑ	mɑ(p)	ti/ʌ	ʤʊ	ɹʊ(k)	fi/ʌ
fu	mu(k)	ti/ʌ	ɹʊ	fʊ(b)	di/ʌ	nɛ	lɛ(g)	zi/ʌ
lɪ	nɪ(d)	zi/ʌ	mæ	gɹæ(p)	li/ʌ	ɹæ	dæ(b)	zi/ʌ
sɪ	wɪ(k)	ði/ʌ	ʔæ	væ(k)	si/ʌ	ku	mu(p)	si/ʌ
dɑ	jɑ(f)	si/ʌ	ʔu	ku(d)	mi/ʌ			

Additional files

The following additional files for this article can be found at https://osf.io/xnp37/

- **File 1.** A tab-delimited text file (`labPhonData`) containing our data and stress transcriptions, as well as acoustic measurements of participants' productions.
- **Files 2 and 3.** Two analysis files, the first an R markdown file (`stressPrime_analysis_notebook.Rmd`), which can be used to run the mixed-effects model in the paper and easily edited to run other analyses on the same data. The second is an html file (`stressPrime_analysis_notebook.nb.html`) which cannot be edited, but in which the details of the analysis can be easily viewed without the use of R.
- **File 4.** An R script (`labPhonPictures.R`).

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Competing interests

The authors have no competing interests to declare.

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