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The Perceptual Nature of Stress Shifts

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Abstract

According to the rhythm rule in metrical phonology, a word's stress alternates from the second syllable to the first when followed by a word with first syllable stress, a situation also known as a stress clash. For example, the second-syllable stressed word sixTEEN will be produced as SIXteen in the phrase SIXteen CANdles. Using pseudo-words in different rhythmic contexts, we demonstrate that stress clash resolution has a strong perceptual component and can be an auditory illusion. In Experiment 1, participants were more likely to misattribute stress in a clash condition (sixTEEN heard as SIXteen in sixTEEN CANdles) than in isolation (sixTEEN) or in a nonclash condition (sixTEEN caNALS). In Experiment 2, we failed to find support for the hypothesis that nuclear stress drove these ratings. We discuss these findings in light of various theories and mechanisms for parsing spontaneous speech.

Keywords: beat clash, rhythm, auditory illusion, nuclear stress, speech perception

The Perceptual Nature of Stress Shifts

Languages such as English and Dutch often have perceptible alternations between strong and weak syllables. To account for this rhythmic variation, considerable attention has been given to the issue of *stress clashes* and their resolution (Grabe & Warren, 1995; Vogel, Bunnell, & Hoskins, 1995; Shattuck-Hufnagel, 1995; Quené & Port, 2002). Stress clashes occur when lexically stressed syllables are adjacent to each other, as in *sixTEEN CANdles*. They are central to understanding how the strong-weak alternation, particularly in English, is created or maintained in the production and perception of speech.

One way that speakers may create the strong-weak alternation is to manipulate the placement of adjacent stress prominences, so that, for example, *sixTEEN CANdles* becomes *SIXteen CANdles*. This phenomenon is known as *stress shift* (Lieberman & Prince, 1977; Cooper & Eady, 1986; Kelly & Bock, 1988; Shattuck-Hufnagel, 1995; Quené, & Port, 2002). Stress shifts can go in one of two directions depending on the language. *SIXteen CANdles* is a *leftward shift* in prominence (*sixTEEN* to *SIXteen*) which is *rightward-driven* (the word on the right, *candles*, influences the pronunciation of the word on the left, *sixteen*). In other stressed-timed languages, *rightward shifts* can be found; for example, *ANziehen* shifts to *den ROCK anZIEHEN* in German (Wagner, & Fischenbeck, 2002). English is thought to have only leftward shifts (Roca & Johnson, 1999). In the current studies, we focus on rightward-driven leftward shifts in English.

We tested whether the perception of stress shifts in English may be driven, perhaps solely, by the relative prominences of the immediately following stressed syllables (Experiment 1) and how these stressed syllables interact with phrasal stress (Experiment 2).

A Faulty Premise: The Primacy of Canonical Stress

Researchers have debated for decades about how to define and identify stress in the acoustic signal (Cutler, 1984; Fear, Cutler, & Butterfield, 1997; Kochanski, Grabe, Coleman, & Rosner, 2005). While much evidence does point to stress patterns as broad indices of language-specific rhythmic patterns (Abercrombie, 1967, Ramus, Nespor & Mehler, 1999), identifying the exact acoustic and phonetic realizations of these stress patterns in spoken talk remains a challenge. For this reason, we restrict our investigation to the long-debated phonological rule of stress-timed languages, the stress shift. We first discuss how this phenomenon has been treated in classical formal linguistic analyses and then turn our attention to several studies that have sought to identify its phonetic manifestation and how it is perceived.

The theoretical ontogeny of stress shift in phonological theories, particularly *metrical phonology* (Lieberman & Prince, 1977), stems from a single critical assumption: *canonical stress*, also called *lexical stress* or *citation form,* is a default, context-free stress pattern that all words have (e.g. Hayes, 1984). This pattern can be altered to accommodate various phrasal contexts. With the primacy of canonical stress assumed, a stress clash occurs when the phrasal environment abuts two strong lexical syllables (e.g., *sixTEEN CANdles*).

In metrical phonology, stress clashes are often described in terms of *metrical grids* (Lieberman & Prince, 1977; Selkirk, 1995; Roca & Johnson, 1999), as in the following:

(1) Metrical Grid of a Stress Clash

*   *

```
*   *     *
*   *     *   *
sixTEEN  CANdles
```

To relieve the stress clash and maintain the preference for a rhythmic alternation between strong and weak syllables, the *rhythm rule* is applied. Application of the rhythm rule causes the speaker to produce the leftmost word in the pair with a stress pattern that is the reverse of the canonical stress, as in the following:

(2) After Application of the Rhythm Rule

```
*         *
*   *     *
*   *     *   *
SIXteen   CANdles
```

So, *sixTEEN* is produced as *SIXteen*, resolving the stress clash *sixTEEN CANdles* into the strong-weak alternation *SIXteen CANdles*. In many metrical accounts, this reversal of canonical stress in the context of an immediately ensuing stressed syllable is known as *iambic reversal* (Liberman & Prince, 1977; Selkirk, 1995).

A different phonological analysis is *accent deletion* or *deletion analysis* (Gussenhoven, 1991; Vogel et al., 1995). In deletion analyses, the primary stress of the second syllable is reduced to secondary stress as follows:

(3) Deletion Analysis of *Sixteen Candles*:

```
    *    *                *
*   *    *          *   *   *
*   *    *   *      *   *   *   *
```

sixTEEN CANdles SIXteen CANdles

Deletion analysis resembles the rhythm rule, and retains the lexical stress assumption.

Contrary to the lexical stress assumption, the production of citation forms seems to depend heavily on phrasal and grammatical variables. Kelly and Bock (1988) demonstrated that speakers produce citation stress patterns to pseudo-words based on grammatical categories (verb vs. noun) and rhythmic context (iamb-biasing vs. trochee-biasing contexts). This suggests that speakers use stress to maintain rhythmic alternation and optimal spacing between strong syllables. In this model, citation form represents a particular grammatical and prosodic environment: an environment with nothing to the left or right. Chomsky and Halle (1968) introduced the notion of *nuclear stress* to account for the interaction of phrasal and lexical stress: The lexical constituent that is the most prominent in the sentence is focused on to become the nucleus of the sentence. Grabe and Warren (1995) argued that words such as *ideal* and *sixteen*, with two stressable syllables, carry nuclear stress in the second syllable in citation form, but have two acoustically equal syllables in non-nuclear and non-phrase final position. Thus, nuclear stress can come about three ways: in isolation contexts (citation form), in phrase-final position, and when words are in the most prominent position in a sentence.

In contrast, postulating a default context-free canonical stress corals metrical phonology into supporting what may be an unnecessary phonological rule, the rhythm rule. An alternative hypothesis is that canonical stress is purely a product of phrasal context[1]. For example, words like *sixteen* are pronounced as *sixTEEN* in isolation because of the nuclear stress rule, and pronounced without an accent in other contexts.

[1] It should be noted that in the limited context of the rhythm rule discussion, we chose to illustrate this point in classic metrical phonology terms (Lieberman & Prince, 1977) for simplicity as well as in keeping with

(4) *Sixteen* in Citation Form:

(*) Phrasal Tier (NSL)

(* *) Lexical Tier

(* *) Foot Tier

sixTEEN

(5) *Sixteen* in Non-Nuclear Position Followed by an Unstressed Syllable:

(* *) Phrasal Tier (NSL)

(* *) (*) Lexical Tier

(* *) (* *) Foot Tier

SixTEEN caNALS

(6) *Sixteen* in Non-Nuclear Position Followed by a Stressed Syllable:

(* *) Phrasal Tier (NSL)

(* *) (*) Lexical Tier

(* *) (* *) Foot Tier

SIXteen CANdles

That is, abutting phrasal contexts will give the illusion of stress shift in some cases (*sixteen* in non-nuclear position followed by a stressed syllable) but not in others (*sixteen* in non-nuclear position followed by an unstressed syllable). Both the concept of canonical stress and the rhythm rule are unnecessary.

Further evidence against canonical stress and the rhythm rule can be gleaned from spontaneous speech production research: Citation forms as the output of phonological

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previous literature. Because of a lack of isomorphism between the syntactic and prosodic domains, a more complex phrasal environment can lead to other grid eurhythmy problems. Thus, a similar but more complete and faithful analysis should be carried out in the framework of nested boundaries as prescribed by prosodic phonology.

encoding must be overwritten in the articulatory output due to constraints such as coarticulation and segmental deletion (Dell, 1986; Levelt, 1989). Listeners therefore need to deal with situations in which rhythmical information cannot always be clearly identified from speakers' natural productions of words in spontaneous speech.

Further support can be gleaned from stress shifts in German (both leftward and rightward), which appear to be primarily perceptually driven (Mengel, 1998): Stress shifts tend to occur less frequently (lower probability) in regards to either their production or perception than traditional phonological accounts suggest (Wagner, 2002; Wagner, & Fischenbeck, 2002). We extend this view to English given the continuing debate over how speakers produce stress shifts and how listeners hear them (Grabe &Warren, 1995; Shattuck-Hufnagel, 1995).

Although the results from German run counter to classical treatments of the rhythm rule (both Reversal and Deletion analyses), they are compatible with an alternate class of phonological analyses, the *Early Pitch Accent accounts* (Beckman and Pierrehumbert, 1986; Beckman & Edwards, 1994; Gussenhoven, 1991; Shattuck-Hufnagel, 1995). According to Early Pitch Accent accounts, what appear to be stress shifts may instead be a predisposition for the speaker to place a pitch accent at the beginning of an intonational phrase. The first syllable of the word *sixteen* is also the first syllable of the phrase *sixteen candles*. The Early Pitch Accent account therefore predicts that the first strong or stressable syllable in a clash as well as the first strong or stressable syllable in a non-clash context may both carry pitch accent (Shattuck-Hufnagel, 1995). The *six* of *sixteen* would be stressed in both *sixteen candles* and *sixteen canals*, with no difference between the two *sixteen*s. The empirical evidence supporting Early Pitch

Accent accounts (Beckman, Swora, Rauschenberg, & de Jong, 1990; and see Shattuck-Huffnagel, 1995 for a detailed discussion) were production based; how the words were heard has not been assessed.

A Possible Alternative: Listener-Imposed Stress Adjustments

Instead of speakers' producing rhythmic alternations, listeners may impose rhythmic alternations on the acoustic information they hear. That is, listeners may perceive the rhythmic pattern of a token differently depending on the context surrounding that token. In early work in this domain, Warren (1970) showed that people perceive the most stressed word of a phrase differently depending on whether that phrase was preceded by a spliced-in pause or not.

The perceptual basis of stress clash resolution is supported by a comparison of the way words were pronounced in stress clash versus non-stress clash contexts (Grabe & Warren, 1995), such as the following (p.97):

(7) Stress clash: When my father watches TV soaps, they're his favorite.

(8) Non-stress clash: When my father watches TV, soaps are his favorite.

The word *TV* in the stress clash context of the noun phrase *TV soaps* is made up two syllables that are virtually identical in acoustic stress as measured by duration and *f0* range. However, 84% of the targets in this stress clash condition (*TV* in *TV soaps*) were heard as having stress shifted to the first syllable (Grabe & Warren, 1995). For comparison, only 3% of the targets in the non-stress clash condition (*TV* in *TV, soaps*) were heard as having stress shifted to the first syllable (Grabe & Warren, 1995).

In a subset of the stress clash items where the all targets were judged to be shifted (i.e., 100% of the listeners rated the stressed syllable as the first syllable), when the subsequent stress-containing word was removed (*soaps* in *TV soaps*), only 67% of the targets were judged to be shifted (an additional 13% were judged unshifted, and 20% were unsure; Grabe & Warren, 1995). When the target was presented in isolation, judgments changed even more dramatically; now, 38% were judged to be shifted, 20% unshifted, and 42% unsure (Grabe & Warren, 1995). This supports their hypothesis that the perception of a strong-weak alternation is driven by the context of the shiftable sequences (Grabe & Warren, 1995).

Based on these results, Grabe and Warren (1995) argued that words with two stressable syllables, such as *TV*, *ideal*, and *sixteen*, should not be treated as having a default, canonical stress on the second syllable. Instead, these words should be viewed as having equal stress except in nuclear and phrase-final positions, when stress shifts to the second syllable. Unfortunately, Grabe and Warren (1995) cannot fully support this claim based on the materials they tested because they did not illustrate that shifts were not heard in non-clash, non-phrase-final conditions. That is, Grabe and Warren (1995) predict that the *TV* in *TV entertainers* would not be heard as stressed on either the first or second syllable. But the Early Pitch Accent account predicts that the *TV* in *TV entertainers* would be heard as stressed on the first syllable if *TV entertainers* is produced as a single intonational phrase.

One difficulty for Early Pitch Accent accounts is the fact that there are cases where the leftward shifts are not observed. Dainora and Hemphill (1996) failed to find production evidence for leftward shifts when testing syllable duration, amplitude, and pitch of spontaneously spoken phrases. Simiarly, Cooper and Eady (1986) found no production evidence for the rhythm rule when phrasal positions were equated across potential stress-shiftable and non-stress-shiftable sequences, as in the following (Cooper & Eady, 1986, p.382):

(9) *Thirteen companies* submitted bids to build the new shopping mall.

(10) *Thirteen corporations* submitted bids to build the new shopping mall.

According to the rhythm rule, *thirteen* in *thirteen companies* creates a clash because in citation form *thirteen* is stressed on the second syllable and *companies* is stressed on the first syllable. At the same time, *thirteen* in *thirteen corporations* does not create a clash because *corporations* is not stressed on the first syllable. Application of the rhythm rule to smooth out the clash predicts that the first syllable of *thirteen* should be stressed in *thirteen companies*, but not in *thirteen corporations*. But no measureable differences were observed in either duration of *f0* of the first syllable of the word *thirteen* across the two situations as well as with similar manipulations across five experiments (Cooper & Eady, 1986). But although these studies convincingly demonstrated that stress shifts were not produced by speakers, they did not test whether stress shifts were heard by listeners.

In Experiment 1 we test whether people perceive the same acoustic token differently in clash and non-clash contexts. In Experiment 2 we test whether stress judgments are influenced by the relative stress prominences of the words following the targets (e.g., Does stressing the word *soaps* in *TV soaps* lead to more reports of *T* being stressed than not stressing the word *soaps*? Does decreasing stress on *soaps* lead to fewer reports of *T* being stressed?).

Because spontaneously produced stress clashes are rare (see Grabe and Warren, 1995; 4% in their data set), stress clashes in the current experiments were achieved artificially by systematically manipulating acoustic parameters related to the perception of the stress in both the target items and context words. The critical feature in both of these experiments is the comparison between hearing the acoustically identical weak-strong targets in isolation versus a stress clashing position.

Experiment 1

Target pseudo-words such as *munsut* were manipulated so that they either had stress on the first syllable or on the second syllable. Stress was defined as both acoustic patterns that were applied to the materials and perceptual judgments of the materials when presented in isolation.

The target pseudo-words were presented either (1) in isolation, (2) followed by a real word stressed on the first syllable, *canon*, or (3) followed by a real word stressed on the second syllable, *canal*. Pairing pseudo-words with real words allowed more experimental control compared to prior studies of stress shift that used only real words. First, pseudo-words control for potential lexical effects of grammatical categories and semantic effects on the perception of stress shifts. For example, the word *address* is stressed on the first syllable when it's a noun, but on the second when it's a verb. Second, pseudo-words eliminate experimental confounds such as frequency and plausibility effects on stress judgments for real words (see McCauley, Hestvik, & Vogel, 2013). Real words were used as the second words in the pairs in order to demarcate one word from the other. This way, listeners would not be in doubt as to where the offset of the pseudo-word was. If the paired sequence were not a pseudo-word plus a real word, listeners might become confused. A sequence of two pseudo-words could be interpreted as a single four-syllable pseudo-word.

According to the rhythm rule, listeners should hear stress on the words in phrases in the same place as they hear stress on the words in isolation, because the target items are acoustically identical. If stress clash resolution is a perceptual phenomenon, however, then listeners should hear the stress pattern of words in the clash condition (a word with weak-strong syllabic pattern followed by *canon*) as shifted (the weak-strong word is heard as strong-weak).

Method

Participants. Forty-four undergraduates at the University of California at Santa Cruz participated in the experiment in exchange for course credit. All participants were native speakers of American English from the Western United States.

Stimuli Creation. Twenty-eight disyllabic pseudo-words were constructed with one strong syllable and one weak syllable. The pseudo-words were variations of genuine words where vowels were held constant but consonants were altered. For example, the pseudo-word *pedane* was created from the word *deplane*. This was done to model as closely as possible the stress-bearing part of genuine words (the vowels), while still allowing novel experimental targets. Appendix A shows the pseudo-words with their respective acoustic measurements. [2]

After the pseudo-words were constructed, they were produced by a single speaker and recorded with Praat (Boersma & Weenink, 2005) at 44100 Hz. Half the pseudo-words were spoken with a strong-weak pattern (*trochaic*) and the half with a weak-strong pattern (*iambic*). Whether a pseudo-word was pronounced in a given pattern depended on

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[2] An anonymous reviewer suggested that the items containing real word syllabic components might bias listeners to report stress on the real word syllables, or to avoid reporting stress the real word syllables. While possible, we note that any such bias was balanced across conditions and would have affected each condition equally.

the ease of pronunciation as well as the original stress pattern of the word that the pseudo-word originated from. This was done to control for properties of syllables that might not be able to be manipulated with PRAAT, such as vowel quality. Whether an item was naturally pronounced with strong-weak pattern or weak-strong pattern was arbitrary. Each natural production was then manipulated to create a second version of that token with the opposite rhythmic pattern. In other words, naturally produced strong-weak patterns were manipulated so that they had an weak-strong pattern and naturally produced weak-strong words were manipulated so that they had a strong-weak pattern. This was done by manipulating both the *f*0 and the amplitude of the corresponding syllables. We chose not to manipulate duration for several reasons. First, many weak syllables had longer durations due to non-stress-bearing segments on consonants, e.g. consonant clusters, frication, aspiration, etc. While the option remained to only manipulate the stress-bearing segment, we were unsure as to the correct procedure for manipulating the relative duration of the non-stress-bearing segments. Second, duration is considered to be less perceptually prominent than *f0* and amplitude in English regarding the acoustic correlates of stress (Lieberman, 1960; Kochanski, Grabe, Coleman, and Rosner, 2005[3]).

Using the Manipulation object in PRAAT, the fundamental frequency of a syllable was multiplied by a factor (in semitones) of 1.2 when increasing pitch values, and by .8 when decreasing pitch values. In some cases where this proportional transformation did not reverse the stress pattern, pitch contours were further manipulated by adjusting the pitch points with the pitch Manipulation function in Praat until there was roughly 30 Hz difference between the averages of all pitch values between the strong and

[3] See Sluijter & Heuven (1996) for conflicting evidence in Dutch regarding the relative importance of duration in the production of stress.

weak versions of a syllable. The mean difference in pitch values across all syllables was 28.22 Hz with a SD of 6.34 Hz. Also, pitch contours were stylized in a way that mimicked the contour of the opposite syllable in the word. For example, if the stressed syllable had a rising contour on the stress-bearing syllable (L-H*), minor adjustments in the pitch stylization process were made to give the opposite syllable a rising pitch contour when changing the stress pattern.

Amplitude was manipulated with Audacity version 1.2.3 until there was roughly a 3 dB difference between each syllable. All naturally produced target (pseudo-) words yielded a mean dB difference 3.4 dB with a SD of .53 dB. Manipulated versions had a mean amplitude difference of 3.2 dB with a SD of .55. The durations of target (pseudo-) words were the same across all conditions. Durations of the second syllables of the pseudo-words were longer than durations of the first syllables (see Appendix 1). If duration is a salient cue for stress, then this should work against our hypothesis: If listeners identify the longer syllables as more stressed, this should prevent listeners from hearing shifts from second syllables to first syllables in the clash condition. Another way of thinking about the duration difference is that any shifts in the clash condition that we do observe might be even greater with matched durations across first and second syllables.

Norming Stimuli. To ensure that the stimuli manipulations were as intended, twenty-two participants listened to the stimuli and determined whether the item they heard was stressed on the first or on the second syllable. Stimuli were presented in counterbalanced lists such that each list contained either the weak-strong or the strong-weak version of each target item (14 of each). Eleven people rated the target items on one list, and the other 11 rated items on the other list.

According to metrical phonology, words that can undergo a stress shift must be stressable; that is, their syllables must receive either primary or secondary stress (Roca & Johnson, 1999). We set a minimum of 64% accuracy of perception of the intended stress pattern because target items whose accuracy was at chance (50%) may not be stressable. Nineteen of the twenty-eight stimuli pairs met this criterion.

Stimuli in Phrases. Seventy-six stimuli phrases were created by combining each of the 38 disyllabic target items (19 pairs) with either the word *canal* or the word *canon*.

After the pseudo-word target items were concatenated with the real words, amplitude of the context words was manipulated so that either *can* in *canon* or *nal* in *canal* was the loudest in each word pair, so the context words would be perceived as the nuclear element rather than the target items. Also, pause duration between words was kept constant at 70 ms, except in the case of stops that had long pauses after the nucleus in a given syllable. In this case, pauses were measured from the end of the nucleus.

Design. Participants were presented with six different conditions of the pseudo-words in a within-subjects design. The conditions were as follows: (1) pseudo-words with a strong-weak pattern, (2) pseudo-words with weak-strong patterns, (3) pseudo-words with strong-weak pattern followed by CANon (strong-weak strong-weak), (4) pseudo-words with a strong-weak pattern followed by caNAL (weak-strong weak-strong), (5) pseudo-words with weak-strong patterns followed by CANon (weak-strong strong-weak), and (6) pseudo-words with strong-weak pattern followed by caNAL (strong-weak weak-strong). From now we refer to the pseudo-words as either strong-weak targets (*trochees*) or weak-strong targets (*iambs*). All items were presented in a new random order for each participant.

Procedure. Twenty-two participants were presented the materials on a MAC G4 using Superlab Version 4 Beta Version 7 using a within-subjects design. Target items were presented binaurally through Plantronics Stereo PC Headset Model 330. Participants also were simultaneously presented with a screen displaying two versions of the stress pattern for each pseudo-word, e.g. MUNsut or munSUT. Participants made a forced choice between these two options. They were instructed to rate only the pseudo-word regardless whether it was presented isolation or with one of the real words. They had an unlimited amount of time to make their decision. After reading the instructions and completing nine practice trials, participants had the opportunity to ask the experimenter any questions pertaining to the task. They then completed the experiment.

Results

Data for four participants were removed from analyses for either not following instructions or for entering only one response on 80% or more of the experimental trials. Inspection of responses in the isolation conditions (1 and 2 above) suggested that two participants adopted a strategy of responding to virtually all items with the key indicating the first syllable, and two participants adopted a strategy of responding to virtually all items with the key indicating the second syllable. In addition, five items were removed from analyses because participants were at chance in their ratings of stress in the isolation condition (50-55% accuracy). For all remaining items, performance was between 60% and 90% correct. The mean response rate, in terms of the proportion of SW judgments, and standard errors for each condition are shown in Table 1. Because the adequateness of

ANOVAs for forced choice categorical measures has come under scrutiny (Jaeger, 2008), a logit mixed model was used to model the percentage of correct judgments for a given stress pattern (strong vs. weak). The model included fixed effects for stress (strong vs. weak), context (*baseline, canal, canon*), and an interaction term for stress and context. The random effects terms for both participants and items were coded using the following random effects structure: (1+ Stress*Clash|Px) and (1+ Stress*Clash|Items) (see Barr, Levy, Scheepers, & Tily, 2013 for a discussion of "maximal" random effects structure and the *minF'* statistic).

There was a reliable interaction between stress (weak-strong or strong-weak) and context (followed by *canal* or *canon*), B[4] = 1.08, $z = 2.9$, $p < .002$, a significant main effect of stress, B = 3.78, $z = 4.24$, $p < .001$, and a marginally significant main effect of context, B = 1.24, $z = 1.89$, $p = .06$. To test the difference between the conditions, we used the same mixed effects model, albeit with the fixed effect of condition as the sole predictor (with 6 levels - SW, WS, SWSW, WSWS, SWWS, WSSW) as well as with the same random effects terms shown above. With the weak-strong target items set as the baseline variable in the model, the weak-strong targets followed by *canon* (stress clash condition) differed significantly from the weak-strong targets in isolation, B = 0.91, $z = 2.97$, $p < .001$, however weak-strong targets followed by *canal* did not, B = 0.07, $z = 0.3$, $p = 0.76$. All of the strong-weak targets differed significantly from the weak-strong targets in isolation, z's > 4.0, p's < .001. That is, listeners' perceptions of weak-strong stress patterns shifted from the second syllable to the first syllable when the weak-strong target was presented before a stress clash (weak-strong strong-weak clash condition).

[4] "B" here refers to the estimates for each level in the model relative to the baseline level. These represent the unstandardized regression coefficients on the logit scale.

They heard stress on the first syllable 26% of the time when the word was in isolation, but 38% of the time when the word was followed by a clashing word. Listeners heard stress on the second syllable 74% of the time when the weak-strong target was presented in isolation and 75% of the time when it was presented before a non-clashing weak-strong context. Correspondingly, listeners heard stress on the first syllable 74% of the time when strong-weak targets were presented in isolation and 72% of the time when presented in strong-weak strong-weak phrases (see Figure 1).

Insert Table 1 and Figure 1 about here

Discussion

There were three key findings. First, stress judgments of the weak-strong targets varied across clash (weak-strong strong-weak) and non-clash (weak-strong weak-strong) contexts -- 39% to 25% were judged to have stress on the first syllable. Second, stress judgments of the weak-strong targets varied across clash and isolation contexts -- 39% to 26% were judged to have stress on the first syllable. And third, stress judgments of strong-weak targets did not differ across weak-strong or strong-weak contexts -- 69% to 74% were judged to have stress on the first syllable..

Although the stress pattern of the subsequent word had a clear effect on the stress judgments of the preceding word, what is not clear is whether the differences found here reflect a general tendency for listeners to impose a degree of separation or spacing in the perception of stress prominences (in a sense, a perceptual equal spacing constraint like the production counterpart proposed by Quené and Port, 2002), or whether the differences reflect relative differences in the magnitude of the stress prominences. This question was examined in Experiment 2.

Experiment 2

In Experiment 2 we tested whether the relative prominence of the stress on the subsequent word affected the perception of stress shift. If stress shifts are affected by relative prominence, then listeners should be more likely to perceive a stress shift when nuclear stress is on the second word in the two-word phrase than when nuclear stress is on the first word in the two-word phrase.

Method

Participants. Forty undergraduates at the University of California at Santa Cruz participated in the experiment in exchange for course credit. All participants were native speakers of English from Northern California.

Materials. The same pseudo-word targets from Experiment 1 were used (14 stimuli pairs). The real words *canon* and *canal* were manipulated to create two versions with differing phrasal prominences. The relative prominence of both the strong and weak syllables (i.e. the whole word *canon* or the whole word *canal*) were either increased or decreased by 4dBs. In addition, the *f0* of the entire word was either increased or decreased by 30 Hz. These changes made *canon* or *canal* either the most prominent word in the phrase or the least prominent. All of the authors independently checked each of the stimuli to ensure that different prominences were easily discriminable. In the *high* condition, nuclear stress was still was on the most prominent syllable in the second word as in Experiment 1. However, in the *low* condition, nuclear stress was on the most prominent syllable in the pseudo-word. Grabe and Warren (1995) concluded that a stress shift is perceived unless the most prominent syllable in the (percieved) stress shifted pair had the nuclear stress of the intonational phrase.

Design. Participants were presented with ten different conditions in a within-subjects design. The conditions were as follows: (1) pseudo-words with strong-weak patterns, (2) pseudo-words with weak-strong patterns, (3) strong-weak pseudo-words followed by high-prominence CANon, (4) strong-weak pseudo-words followed by low-prominence CANon, (5) strong-weak pseudo-words followed by high-prominence caNAL, (6) strong-weak pseudo-words followed by low-prominence caNAL, (7) weak-strong pseudo-words followed by high-prominence CANon, (8) weak-strong pseudo-words followed by low-prominence CANon, (9) weak-strong pseudo-words followed by high-prominence caNAL, (10) weak-strong pseudo-words followed by low-prominence caNAL. All items were presented in a new random order for each participant.

Stimuli were presented in two lists that counterbalanced high- and low-prominence items. Each participant completed only one list. In this way, no participant heard the same combination of stress patterns and words more than once. That is, a participant either heard *munSUT CANon* with high prominence or *munSUT CANon* with low prominence, not both.

Procedure. The procedure is the same as for Experiment 1. The only difference is that Version 4.0.1of Superlab was used.

Results

Data for one participant were removed from analyses for entering only one response on 80% or more of the experimental trials. To maintain an even number of participants across lists, an additional participant was excluded. As in Experiment 1, items whose ratings of stress in isolation were either at chance or at ceiling were removed from analysis. One additional item was randomly selected for removal to maintain an even number of items per condition. Sixteen items remained for which performance was between 60% and 90% correct. Because the design of the current experiment is an incomplete factorial (i.e., there is no high-low manipulation for the strong-weak and weak-strong targets in isolation), the analysis was carried out as follows: (1) a 2 x 2 x 2 logic mixed-effects model with Stress, Context, and Prominence as fixed effects excluding the baseline line conditions, and (2) a 2 x3 logit mixed-effects model with Stress (strong vs. weak) and Context (baseline, clash, non-clash) as fixed-effects, however collapsed across prominence (the same exact model as in Experiment 1). The models included the same random effects structure used in Experiment 1. The mean response rates, in terms of the proportion of stress on the first syllable (SW judgments) and their respective standard errors for the prominence analyses, are displayed in Table 2 and in Figure 2. The mean response rates collapsed across prominence for comparison to Experiment 1 are displayed in Table 3.

Analysis of Stress, Context, and Prominence (without baseline conditions). A 2 x 2 x 2 logit mixed effect model found the same interaction of Stress and Context in Experiment 1, B = 1.04, $z = 2.3$, $p < .03$. However, it failed to failed to find any main effects of stress and context when prominence was included as another fixed effect in the model, z's <.8, p's > .5. Critically, the three-way interaction between Stress, Context, and Prominence and the other two-way interactions of Stress and Prominence as well as Context and Prominence were also not statistically significant, z's < 0.35, p's > .7. The single factor mixed effects model used in Experiment 1, albeit without the baseline conditions, was used to examine whether high vs. low prominence levels for weak-strong targets followed by *canon* differed significantly and whether they differed from other prominence levels in the other stress and context conditions. Critically, high vs. low prominent levels did not differ significantly form one another, B = 0.13, $z = 1.02$, $p > 0.3$, however the low prominence versions of the stress clash condition differed significantly from all of the other prominence levels across the Stress x Clash conditions, z's > 4, p's < 0.01

Insert Tables 2 & 3 and Figure 2 & 3 about here

Analysis of Stress and Context (with baseline conditions). By collapsing across Prominence, the same 2 x 3 model from Experiment 1 could be applied to the Experiment 2 data. A significant main effect of Stress was replicated by the model, B = 2.12, $z = 8.69$ $p < .001$, however there was no significant effect for Context, B = 0.03, $z = 0.23$, $p = .83$. Critically, the interaction of Stress x Context was also replicated, B = 1.04, $z = 2.32$ $p < .02$.

The same single factor mixed-effects model in Experiment 1 was used to test the same comparisons between weak-strong targets in isolation and weak-strong targets in the clash condition. Weak-strong targets in isolation again differed significantly from weak-strong targets followed by *canon*, B = 0.91, $z = 2.9$, $p < 0.01$, however not when weak-strong targets were followed by *canal*, B = 0.07, $z = 0.28$, $p = 0.76$. That is, listeners' perceptions of weak-strong stress patterns shifted from the second syllable to the first syllable when the weak-strong target was presented before a stress clash (weak-strong strong-weak clash condition). They heard stress on the second syllable 78% of the time when the word was in isolation and 80% of the time when it was presented before a non-clashing weak-strong context, but only 57% of the time when it was followed by a clashing word.

Discussion

In Experiment 2, we replicated the effects found between the two clash contexts in Experiment 1. While the percentages of high and low prominence variants altered stress-rating judgments in different directions for the clash conditions, a lack of a significant three-way interaction (Stress x Context x Prominence) and a comparison in the mixed model between the clash context with high and low prominences showed that this difference was not statistically significant.

Experiment 2 ruled out the possibility that the perception of nuclear stress drove participants' judgments of stress-shifted items in Experiment 1. Listeners were not more likely to perceive a stress shift in the high prominence condition (nuclear stress condition) than the low prominence condition (non-nuclear stress condition). In fact, listeners were less likely to perceive a stress shift in WS SW pairs when the second word in the pair had nuclear stress, although this interaction was not significant.

The Early Pitch Accent account (Shattuck-Hufnagel, 1995) can plausibly explain some of these findings. According to this account, speakers will generally place a pitch accent at the beginning of the phrase in stress clash conditions when the terminal event is non-nuclear. This explains the finding that WS SW-low pairs are judged as shifted more than WS SW-high pairs. This account does not make predictions for the WS WS-low and WS WS-high pairs because they are not clashing. We observed that the WS WS-low pairs were judged as shifted less than WS WS-high pairs (that is, stress was - incorrectly - attributed to first syllable less in the non-nuclear condition). This pattern mirrors the shifting for the WS SW clashing conditions.

Another explanation is that listeners are biased to hear speech with alternating strong-weak stress patterns. In the WS WS pairs, the WS WS-high appears to reinforce the alternation more than WS WS-low, much like a strongly-beated rhythm may reinforce regularity more than a weakly-beated rhythm. In the WS SW cases, the stronger clash in the WS SW-high cases may prevent rhythmic shifting to SW SW-high, where the WS SW-low cases allow it. This is a different explanation from the Early Pitch Accent account because it focuses on nuclear stress preventing a shift rather than non-nuclear stress allowing it.

General Discussion

Many conflicting production-based accounts have sought to find the acoustic correlates of stress shift (Lieberman & Prince, 1977; Gussenhoven, 1991). We agree that production components can exist. However, using a tightly controlled forced-choice experiment, we demonstrated that stress shift phenomena are strongly perception-based. Put differently, the phonetic components of a stress shift do not need to be available in the acoustic signal in order for listeners to perceive a stress shift.

In two experiments we found a strong effect for the perception of a stress shift in clashing novel word pairs (WS-SW). Because this effect was only slightly amplified when the magnitude of nuclear stress was increased (Experiment 2), we conclude that the perception of stress shift is not simply a matter of prosodic context (Grabe & Warren, 1995). Instead, the perception of stress shift might result from a parsing mechanism that overwrites low-occurrence stress patterns such as a stress clash by imposing alternating stress patterns onto arrhythmic speech.

It is possible that a different pattern might be observed at a neuronal level than the one we observed with a verbal report. McCauley et al. (2012) have shown with EEG (Electroencephalography) measurements that there can be a discrepancy between the immediate neural recognition of acoustic patterns and the later report of stress judgments. In our case, listeners' EEGs may have been similar across stress clash items, even though some of the stress clashes were reported as shifted. However, it's unclear whether pseudo-words would show the same differences between neural recognition and stress judgments as observed with the real words of McCauely et al. (2012). A production bias cannot fully explain our data because speakers had no lexical knowledge of the novel words. That is, even if participants first correctly identified the acoustic properties and then reinterpreted the clash items as non-clash, this would have to be done at a phonological level because the novel words assured that no previous lexical knowledge (i.e. internal generation) was available.

Why do listeners perceive a stress shift where there is none? While many acknowledge that stress shift is optional from a production perspective (Selkirk, 1995), the selective application of this rule from the speaker might be largely irrelevant: Listeners do not seem to need reliable acoustic cues to perceive a stress shift. Our finding is consistent with other well-known experimental findings in psycholinguistics showing that bottom up information does not always determine conscious perception, such as the *phoneme restoration effect* (Warren, 1970; Warren & Sherman, 1974; Samuel, 1981). We argue that because listeners expect rhythmic alternations in stress-timed languages, they impose stress shifts onto arrhythmic input (clash conditions) in a manner similar to phoneme restoration.

We further propose that listeners might rely on a rhythmic parsing mechanism similar to that proposed by Quené and Port (2002). Specifically, we consider a more listener-oriented version of Quené and Port (2002)'s *Equal Spacing Constraint* informed by Mattys, White, and Melborne (2005)'s *Hierarchy of Multiple Cues*. In the Equal Spacing Constraint, speakers place prominent syllables in temporally equal cycles. The difference between the Equal Spacing Constraint and the Early Pitch Accent account is that rhythmical patterns are constrained more by actual temporal intervals and not just abstract time-independent phonological rules. A perceptual mechanism that operates on this principle would seek out equal spacing between prominent syllables. However, exactly what type of acoustic information listeners use to create such parsing units is an ongoing debate in the word segmentation literature, which we turn to now.

Why might listeners hear stress shifts when the relevant phonetic and acoustic cues are not available in the speech stream? Mattys et al. (2005) have offered a concrete framework that provides the rankings of cues in the relative order of their impact on word segmentation. In *laboratory* (read) speech, listeners should have every phonetic cue available in the speech stream despite the low probability of these cues being simultaneously available in spontaneous speech. In this case, Mattys et al. show that lexical information (Tier 1) takes precedence in segmenting words, i.e. identifying word boundaries. According to their findings, segmental and metrical prosody play a significant, albeit less prominent role -- Tier 2 and Tier 3 respectively. Dilley, Mattys, and Vinke (2010) further found that the rhythmical patterns in upcoming speech largely outweighed strong proximal prosodic cues when determining the lexical stress of adjacent segments. This suggests that upcoming prosody might play just as important a role as lexical information (Tier 1).

The findings from our study can be explained in both the Mattys et al. (2005) framework as well as the Dilley et al. (2010) approach. In our study, the absence of lexical information in the pseudo-words might force listeners to rely on the lexical information provided by the second word (*canon* or *canal*) when judging the relative stress patterns of stress clashing syllables. This information might outweigh the Tier 2 information (segmental information) because in our study this information remains the same across conditions. The lack of significant effects for nuclear stress might also be explained by metrical information's occupying the lowest position in the framework (Tier 3). While our experiments did not present an upstream sentential context, one could speculate that having had such a context might have strengthened the differences between the clash and non-clash conditions.

Both a perceptual version of the equal spacing constraint and the integration of multiple cues might be susceptible to the probabilities of stress combinations. The high frequency of alternating stress patterns in English primes listeners to expect alternating patterns. Because produced stress shifts appear to be extremely rare metrical events, listeners' parsing mechanisms may over-ride stress patterns that violate an alternating strong-weak pattern. This idea fits well with phonological perspectives that acknowledge the importance of phonetic probability in phonological representation (Pierrehumbert, 2003). An examination of the relative frequency of lexical stress patterns and the phrasal contexts of stress shifts in spontaneously-produced conversations would provide further evidence relevant to the validity of the claim that stress shifts are more illusory than acoustic[5]. While it might be possible that speakers occasionally produce stress shifts, our findings show that listeners do not require stress-shifted acoustic input in order to perceive stress shifts.

[5] Temperly (2009) is the only work that we are aware of that has examined contextual-specific stress variants of citation forms in a spontaneous speech corpus. Temperly (2009) found that contextual stress patterns do not increase (they actually decrease) the regularity of strong-weak alternations, providing further evidence that speakers do not produce the stress shift.

References

Abercrombie, D. (1967) *Elements of General Phonetics*. Edinburgh: Edinburgh University Press

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random-effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*, 255-278.

Beckman, M. E., & Edwards, J. (1994). Articulatory evidence for differentiating stress categories. In P.A. Keating (Ed.), *Phonological Structure and Phonetic Form: Papers in Laboratory Phonology III* (pp. 7-33). Cambridge University Press.

Beckman, M. E. & Pierrehumbert, J. (1986). Intonational Structure in English and Japanese. *Phonology Yearbook*, *3*, 255-310.

Beckman, M. E., Swora, M. G., Rauschenberg, J., & de Jong, J. (1990). Stress shift, stress clash, and polysyllabic shortening in a prosodically annotated discourse. *Proceedings of the 1990 International Conference on Spoken Language Processing*, Vol. 1, pp. 5-8.

Boersma, P., & Weenink, D. (2005). PRAAT: Doing phonetics by computer (Version 4.3.14) [Computer program]. Retrieved from http://www.praat.org/.

Chomsky, N. & Halle, M. (1968). *The Sound Pattern of English*, New York: Harper and Row

Cooper, W. E. and Eady, S. J. (1986). Metrical phonology in speech production. *Journal of Memory and Language, 25*,369-384.

Cutler, A. (1984). Stress and accent in language production and understanding. In D. Gibbon (Ed.), *Intonation, Accent, and Rhythm: Studies in discourse phonology*. (pp. 77-90). Berlin: Walter de Gruyter.

Dainora, A. & Hemphill, R. (1996). Rhythmic factors and contrastive stress in spontaneous speech. LabPhon 5: Fifth Conference on Laboratory Phonology 5, Evanston, Illinois. GISSL workshop, Girona, Spain.

Dell, G S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review, 93*, 283-321.

Dilley, L. C., Mattys, S.,Vinke, L. (2010). Potent prosody: Comparing the effects of distal prosody, proximal prosody, and semantic context on word segmentation. *Journal of Memory and Language, 63*, pp. 274 – 294.

Fear, B. D., Cutler, A. & Butterfield, S. (1997). The strong/weak syllable distinction in English. *Journal of the Acoustical Society of America 97(3)*, 1893-904.

Grabe, E, & Warren, P. (1995) Stress shift: do speakers do it or do listeners hear it? In B. Connell & A. Arvaniti (eds.) *Phonology and phonetic evidence: papers in Laboratory Phonology 4,* (pp. 95-110). Cambridge: Cambridge University Press.

Gussenhoven, C. (1991) The English rhythm as an accent deletion rule, *Phonology, 8*, 1-35.

Hayes, B.P. (1984). The phonology of rhythm in English. *Linguistic Inquiry*, *15*, 33-74.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation of not) and towards Logit Mixed Models. *Journal of Memory and Language, 59,* 434-446.

Kelly, M. H, & Bock, J. K (1988). Stress in time. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 389-403.

Kochanski, G., Grabe, E., Coleman, J. and Rosner, B (2005). Loudness predicts prominence; fundamental frequency lends little. *The Journal of the Acoustical Society of America, 118**(2), 1038-1054.

Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge, MA: MIT Press.

Lieberman, P. H. (1960) Some acoustic correlates of word stress in American English, *Journal of the Acoustical Society of America*, *32(4)*, 451-454.

Lieberman, M. and Prince, A. (1977). On stress and linguistic rhythm. *Linguistic Inquiry 8*, 249-336.

Lieberman, P. H. & Prince, A. (1977). On stress and linguistic rhythm. *Linguistic Inquiry*, *8*, 249-336.

Mattys, S.L., White, L., & Melhorn, J.F. (2005). Integration of multiple speech segmentation cues: A hierarchical framework. *Journal of Experimental Psychology: General, 134*, 477-500.

McCauley, S. Hestvik, A. & Vogel.I. (2013) Perception and bias in the processing of compound versus phrasal stress: Evidence from event-related brain potentials. *Language and Speech, 56(1)*, 23-44.

Mengel, A. (1998). *Deutscher Wortakzent: Symbole, Signale* [German

Lexical Stress: Symbols and Signals]. Technische Universität Berlin, Berlin.

Pierrehumbert, J. B. (2003). Phonetic diviersity, statisitical learning, and aquisition of phonology. *Language and Speech*, *46*(2-3), 115-154.

Quené, H., & Port, R. F. (2002). Rhythmical factors in stress shift. Paper presented at the 38th Meeting of the Chicago Linguistic Society, Chicago.

Ramus, F., Nespor, M., & Mehler, J. (1999). Correlates of linguistic rhythm in the speech signal. *Cognition, 73*(3), 265-292.

Roca, I. & Johnson, W. (1999). *A course in phonology*. Oxford: Blackwell.

Samuel, A. G. (1981). Phonemic restoration: Insights from a new methodology. *Journal of Experimental Psychology: General, 110,* 474-494.

Selkirk, E. (1995). *Sentence prosody: Intonation*, stress, and phrasing. In J. Goldsmith (ed.), *The Handbook of Phonological Theory*, 550 – 569. Cambridge, MA: Blackwell.

Shattuck-Hufnagel, S. (1995). The importance of phonological transcription in empirical approaches to"stress shift" vs. "early accent": comments on Grabe and Warren, and Vogel, Bunnell and Hoskins. In B. Connell & A. Arvaniti (eds.) *Phonology and phonetic evidence: papers in Laboratory Phonology 4,* (pp. 128-140). Cambridge: Cambridge University Press.

Sluijter, A., van Heuven, V. (1996). Spectral balance as an acoustic correlate of linguistic stress. *Journal of the Acoustic Society of America, 100* (4), 2471-2485

Temperley, D. (2009). Distributional stress regularity: A corpus study. *Journal of Psycholinguistic Research, 38*, 75-92.

Vogel, I. H., Bunnell, T., & Hoskins, S. (1995) The phonology and phonetics of the rhythm rule. In B. Connell & A. Arvaniti (Eds.) *Phonology and phonetic evidence: papers in Laboratory Phonology 4,* (pp. 111-127). Cambridge: Cambridge University Press.

Wagner, P. & Fischenbeck, E. (2002). *Stress perception and production in German Stress Clash Environments* [The Prediction and Perception of German Intonation Patterns]. Paper presented at the Speech Prosody, Aix-en-Provence.

Wagner, P. S. (2002). *Vorhersage und Wahrnehmung deutscher Betonungsmuster*. Rhenischen Friedrich-Wilhelms-Universit'at zu Bonn, Bonn.

Warren, R. M. (1970). Perceptual restoration of missing speech sounds. *Science, 167*, 392-393

Warren, R. M. & Sherman, G. L. (1974). Phonemic restoration based on subsequent context. *Perception & Psychophysics, 16*(1), 150-156.

Table 1. Experiment 1 mean percentage of judgments of stress on the first syllable (standard deviation) for WS and SW targets by context..

	Isolation	WS (*Canal*)	SW (*Canon*)
WS Targets	26.2% (5.3%)	25% (4.4%)	38.5% (4.5%)
SW Targets	74.3% (4.3%)	69.4% (5.3%)	72.2% (4.8%)

Table 2. Experiment 2 mean percentages of judgments of stress on the first syllable (standard deviation) for WS and SW targets by prominence (expressed on *canal* and *canon*) and context (*canal* or *canon*).

	Prominence	WS (*Canal*)	SW (*Canon*)
WS Targets	High	19.7% (3.5%)	40.6% (3.8%)
	Low	18.8% (2.9%)	43.7% (4.2%)
SW Targets	High	68.5% (2.8%)	68.8% (4%)
	Low	69.9% (.3.6%)	67.1% (3.9%)

Table 3. Experiment 2 mean percentages of judgments of stress on the first syllable (standard deviation) for WS and SW targets by context.

	Isolation	WS (*Canal*)	SW (*Canon*)
WS Targets	22.4% (2.5%)	19.4% (2.9%)	41.8% (3.6%)
SW Targets	70% (3.1%)	68.4% (3%)	69.5% (3.5%)

Figure 1

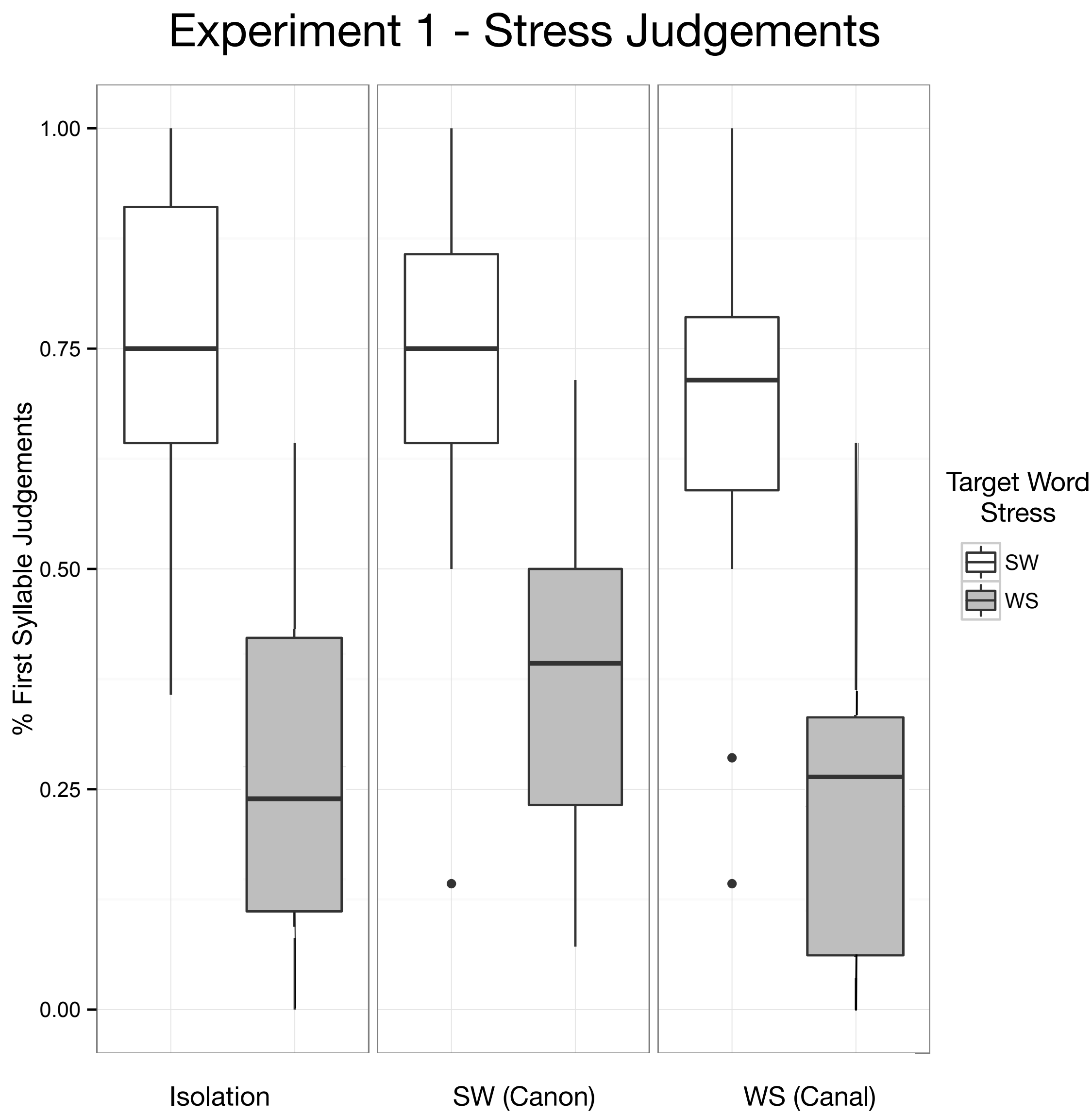

Figure 1. The mean stress judgements for participants for Experiment 1. The y-axis depicts average stress judgements for first syllable judgements. The x-axis corresponds to the different stress context contexts: Isolation, SW (Canon), WS (Canal).

Figure 2

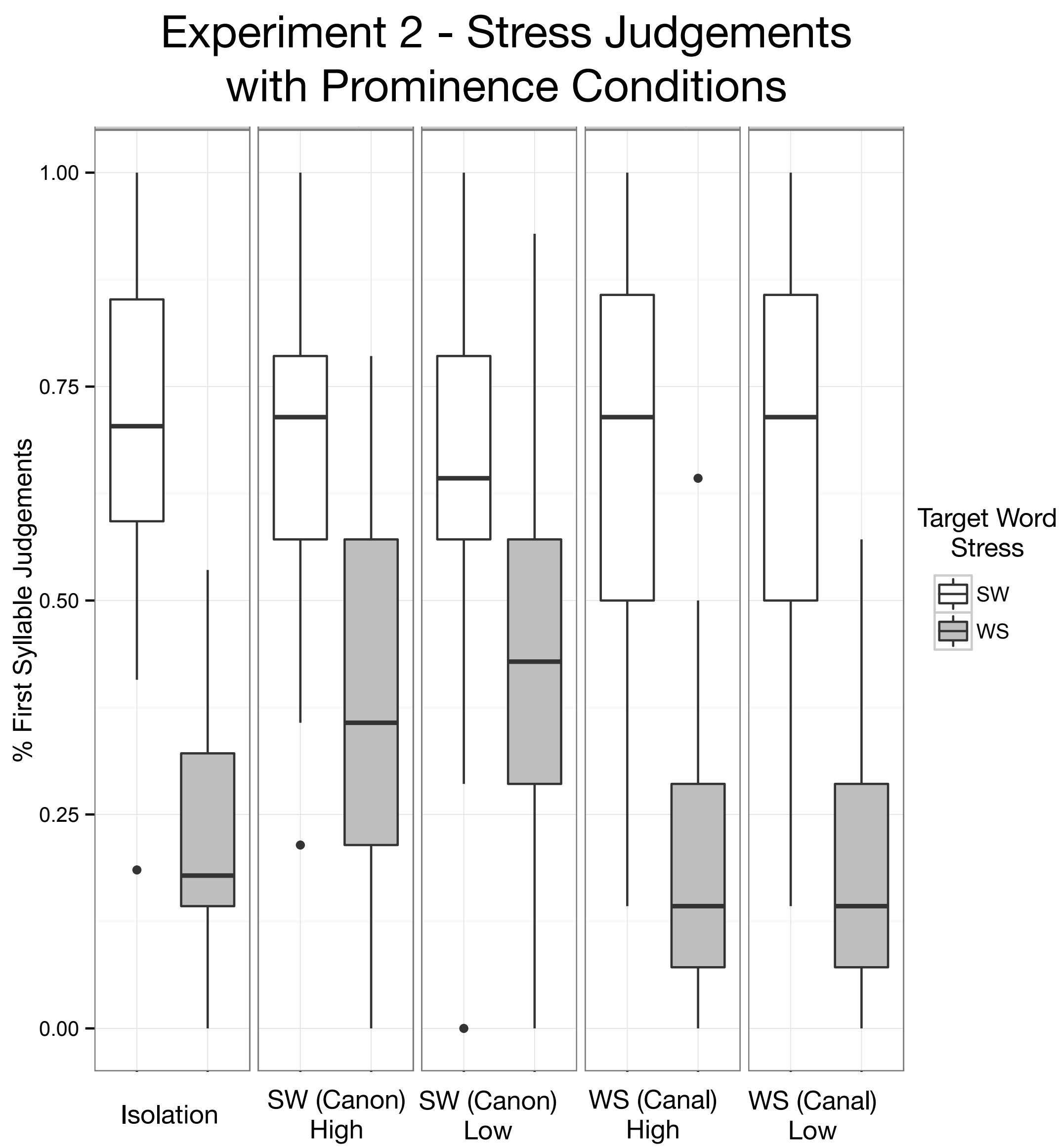

Figure 2. The mean stress judgements for participants for Experiment 2 with the prominence conditions. The y-axis depicts average stress judgements for first syllable judgements. The x-axis corresponds to the different stress contexts: Isolation, SW (Canon), WS (Canal) across the nuclear stress conditions (High & Low).

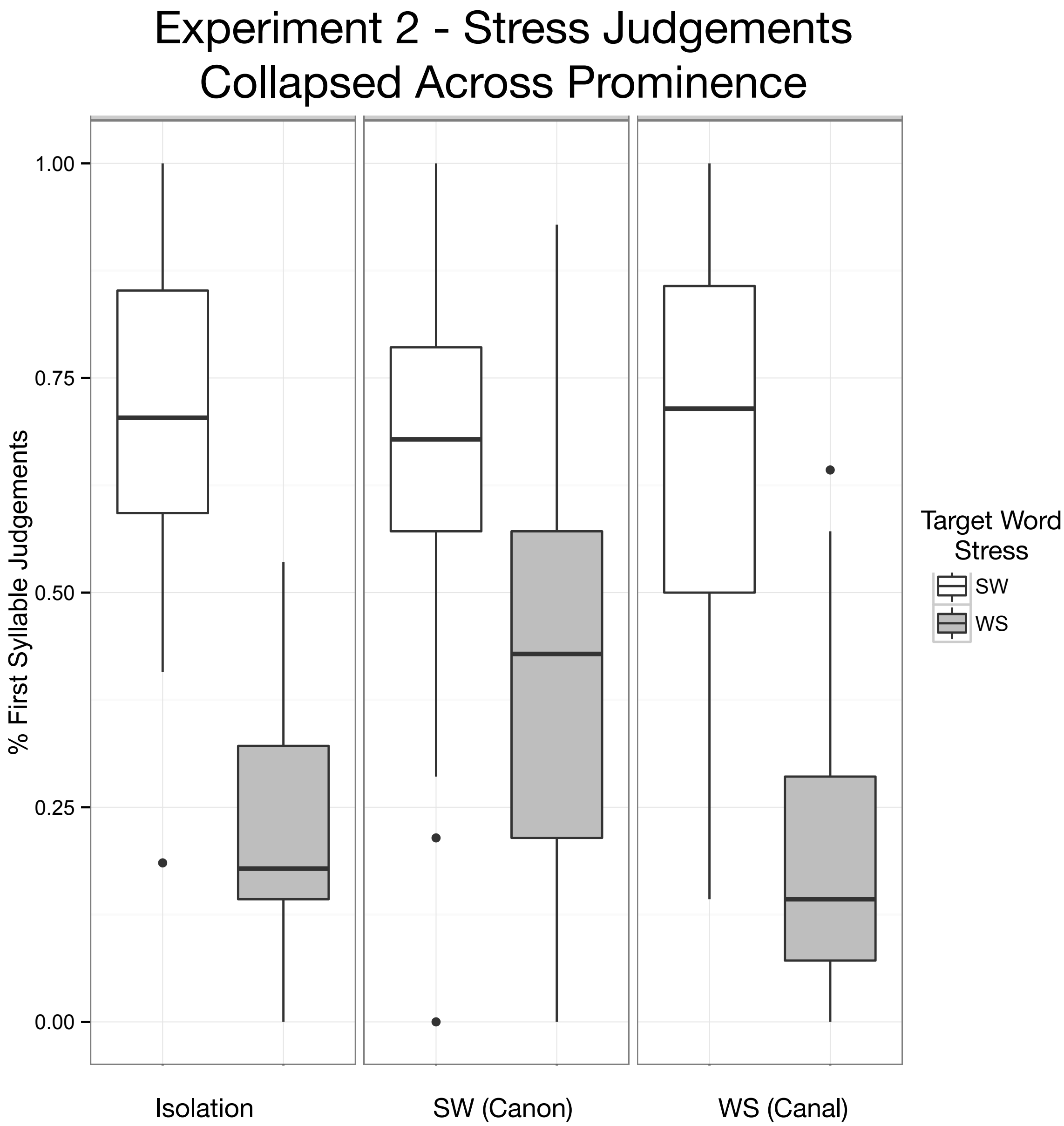

Figure 3. . The mean stress judgements for participants for Experiment 2 collapsed across the prominence conditions. The y-axis depicts average stress judgements for first syllable judgements. The x-axis corresponds to the different stress contexts: Isolation, SW (Canon), WS (Canal).

Appendix 1

Acoustic measurements for stress shiftable stimuli.

Pseudo-word	First Syllable			Second Syllable		
	Hz	dB	duration in msecs	Hz	dB	duration in msecs
BINtool*	136	74	390	102	70	557
binTOOL	107	69	-	132	74	-
DINhue*	143	76	341	91	71	432
dinHUE	108	70	-	134	73	-
Dungee	142	75	386	98	70	317
dunGEE*	105	69	-	144	73	-
FEduce	197	74	286	115	69	531
feDUCE*	123	72	-	148	75	-
FOMdool	157	80	357	96	75	371
fomDOOL*	129	77	-	151	80	-
GISdive*	148	72	321	119	67	495
gisDIVE	116	68	-	146	72	-
GUNlound*	138	73	297	103	66	432
gunLOUND	100	70	-	120	75	-
HINsore	120	73	432	93	69	456
hinSORE*	99	68	-	126	74	-
HUPgil	121	76	397	105	72	439
hupGIL*	109	73	-	138	77	-
KANmin*	141	69	432	113	65	622
kanMIN	103	69	-	133	73	-
LISmay	116	72	427	89	69	468
lisMAY*	106	68	-	122	72	-
MINdeen*	127	75	337	92	71	474
minDEEN	110	71	-	139	75	-
MUNsut	147	78	279	110	73	531

munSUT*	109	74	-	141	78	-
NALpight	142	78	238	101	74	362
nalPIGHT*	101	73	-	119	77	-
PACmutch	145	72	316	114	66	664
PacMUTCH*	109	68	-	135	72	-
PAMdane	135	73	364	106	69	451
pamDANE*	104	68	-	128	72	-
RALdord*	129	78	327	100	72	564
ralDORD	103	73	-	127	78	-
REGmead*	132	71	269	96	66	386
regMEAD	102	68	-	128	73	-
SENged*	138	74	282	112	69	320
senGED	101	69	-	131	73	-
SHEbode	136	72	325	104	69	455
sheBODE*	108	68	-	145	74	-
TEBrud*	126	72	363	99	68	670
tebRUD	104	68	-	130	75	-
TErone	140	73	345	113	68	387
teRONE*	101	69	-	134	73	-
THOUbord	132	75	505	98	67	631
thouBORD*	102	69	-	128	71	-
TIMshin	141	75	294	115	69	478
timSHIN*	107	72	-	142	75	-

***Star** (*) indicates the original version. No star indicates the manipulated version.*