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The Role of a Domain-Specific Language Mechanism in Learning Natural and Unnatural Stress

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Abstract: In an artificial language-learning task, two groups of English and French participants learned one of two language rules: 1) stress the first heavy (CVC) syllable, else the first syllable, or, 2) stress the first light (CV) syllable, else the first syllable. French and English participants were chosen to compare learning outcomes by speakers of different native stress systems, fixed and variable. Participants were trained on the target language by listening to a set of nonsense familiarization words exemplifying the stress rule. This was followed by a forced-choice task to choose the correct version of the words they had just learned. Following the training procedure, participants were tested on novel words with the same stress pattern to which they were familiarized. The result of the novel word testing was that the natural rule with stress on heavy syllables was learned significantly better than the unnatural, stress light syllables, rule. To account for the learnability of both the natural and the unnatural rules, I argue for the interaction of a general cognitive mechanism that facilitates learning in general and a domain-specific language mechanism that can access universal phonological principles to aid in learning a natural language rule.

Keywords: phonology; stress; artificial language learning; domain-general; domain-specific; French stress 'deafness'

1 Introduction

The nature of the mechanism by which humans learn language is an ongoing topic of high interest in linguistics and cognitive science. One view, held by Chomsky and others, is that as a result of evolution, humans have developed a specialized language-learning mechanism, a language-specific module, in the brain (Chomsky, 1965, 1972; Pinker, 1994). A differing view is that there is no language-specific module, but rather, language is a product of generalized cognitive mechanisms that have been co-opted for use in the world's grammars (Bybee, 2006; Christiansen & Chater, 2008), most likely through cultural evolution. This latter perspective sees language as an adaptation or exaptation of existing capacities in the brain, while the former one places the emphasis on language-specific mechanisms in the brain that are 'hard-wired' for language (see Buss, Haselton, Shackelford, Bleske, & Wakefield, 1998) for a review of these terms and perspectives). These views are frequently invoked in studies of child language acquisition. However, they also have implications for second-language acquisition since research has shown that adult learning of a second language demonstrates at least some access to universal features of language (Goad & White, 2008; White, 1990). Are those universal features due to a language-specific endowment, or are they the product of overall cognition?

Based on previous and current research into learning of natural and unnatural stress systems, I argue for an intermediate position, where a domain-specific language mechanism works with general cognition

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to enable the learner to better acquire a natural grammatical rule. While there are many definitions of the term 'natural' in generative grammar (Chomsky & Halle, 1968; Stampe, 1973), I use 'natural' to refer to patterns that are observed cross-linguistically, with rules or features that are typologically prevalent in the world's languages, and 'unnatural' to patterns that are either typologically rare or not attested in language. One form of naturalness, a phonetic precursor, indicates that there is a phonetic basis for a phonological principle being studied. This phonetic basis, sometimes referred to as a 'channel bias' (Moreton, 2008; Yu, 2011), facilitates learning of a phonological rule or principle by exploiting built-in physical aspects of our articulatory system. For example, a phonological pattern of vowel height harmony might be due to the phonetic precursor of vowel-to-vowel height coarticulation (Ohala, 1994). The acoustic correlates of stress are duration, intensity, pitch and spectral balance[1] (Fry, 1955, 1958; Sluijter & van Heuven, 1996). Stressed syllables tend to be longer, louder, and higher in pitch and acoustic energy than unstressed syllables. A possible phonetic precursor to stress being attracted to heavy syllables could be the increased duration and/or perceptual energy of heavy syllables over light ones (Gordon 2002, 2004). However, acquiring a phonological principle can also occur by means of an analytic bias, a form of cognitive bias that facilitates learning (Moreton, 2008; Moreton & Pater, 2012a). Analytic biases provide an explanation of why some phonological patterns are easier to learn than others. The easier-to-learn patterns often reflect systematic generalizations observed cross-linguistically, such as nasal assimilation (Wilson, 2003), preferred onset clusters (Berent, Steriade, Lennertz, & Vaknin, 2007) and stress attraction to low vowels (Carpenter, 2010). The idea behind an analytic bias is that learners are able to tap into innate knowledge of properties of language to enhance their ability to acquire that property. While both channel and analytic biases are natural, an analytic bias often can allow phonological learning even when a phonetic correlate has been neutralized, such as in equalized vowel heights for high and low vowels in stress attraction (Carpenter, 2010), or when the phonetic precursor for two processes are equally robust (Moreton, 2008, 2009). Analytic biases could thus be described as being more abstract than channel biases. Analytic biases can be based in Universal Grammar but are not exclusively so (Saffran, 2003).

Recent research into the learning of natural and unnatural pairs of artificial languages has often demonstrated that it is easier to learn a phonological rule that is based on either typological or phonetic naturalness in language than an equal, but unnatural, version of the same rule (Becker, Nevins, & Levine, 2012; Finley, 2011; Hayes, Zuraw, Siptár, & Londe, 2009; Kapatsinski, 2013; Moreton, 2008; Wilson, 2006). For a recent review see (Culbertson, 2012; Moreton & Pater, 2012a, 2012b). This effect has been seen in a variety of phonological domains including segmental processes (Finley & Badecker, 2010; Wilson, 2006), phonotactics (Pater & Tessier, 2005), tone sandhi (Zhang & Lai, 2010) and stress based on vowel height (Carpenter, 2010). These experiments build on the premise that two patterns of language that are formally equal should be equally learnable if phonological naturalness plays no role in the learning. However, if the natural, typologically frequent, version is learned better than the unnatural, typologically rare or unattested version, then the implication is that the learning process is affected at least in part by an analytic bias, presumably due to a cognitive specialization for language. A channel bias could be eliminated by either neutralizing phonetic cues or by choosing two conditions with equally robust phonetic precursors.

The pattern of rule learning in these artificial language learning experiments also provides some evidence for the role of general cognition. Teasing apart the role of general cognition and that of a language-specific learning mechanism is a daunting task, in part because we have not fully defined all the cognitive mechanisms used in general learning. However, we know that general learning involves memory, aided by frequency and repetition, among other general cognitive mechanisms (Ausubel, 1965; Ellis & Collins, 2009). If language learning includes a domain-specific mechanism, then one way to tease apart the roles of general cognition and a domain-specific language mechanism would be to set up a task that requires general cognition and a separate task that would demonstrate the effect of a domain-specific cognition for those learning a natural language rule but not for those learning an unnatural rule. Both tasks involve the general cognitive mechanism, but only the natural language rule would be additionally facilitated by the domain-specific mechanism. In such a test, all participants should perform equally

1 Intensity differences across frequency bands (Sluijter & van Heuven, 1996).

well on the general cognitive task but a difference should emerge between performance on the natural linguistic task and the unnatural one. In this type of experiment the input is strictly controlled, and the natural rule is crosslinguistically attested but the formally equal unnatural rule is not. Both rules need to be learnable through our general cognitive mechanism; however, the learning of one rule, since it is based on a well-instantiated linguistic distinction, would be advantaged by a mechanism that is specialized for language. If there is no mechanism that aids language, then both rules should be equally well learned since the general cognitive mechanism should handle all the learning, showing no advantage for a linguistic rule. Evidence for the operation of this language-specific mechanism would be improved performance on the typologically natural linguistic rule over the unnatural or unattested one, which might still be at least partially learned as a result of participants' general cognitive abilities, although less well than the natural linguistic rule.

This paper reports on such an investigation, a previously unreported learning bias for syllable weight, where heavy syllables are favored over light syllables for stress attraction. I compare a typologically natural rule to its opposite, an unnatural version that produces a phonological stress pattern that is unattested in language. This manipulation creates two rules that can be pitted against each other. The rules are equally formally complex and thus should be equally learnable under a general cognitive mechanism. However, if learning of the natural rule is enhanced because adults can access a language-specific learning mechanism, then a difference in the learnability of the two rules should emerge.

The experiments presented in this paper were conducted with English and French speakers who were exposed to either a natural or an unnatural stress rule based on syllable weight. The aim of the research was to examine whether the natural version would be learned better than the unnatural one overall. Both English and French speakers were used to examine the effects of the native stress pattern on the learning of a novel stress rule. For speakers of a language in which stress is attracted to heavy syllables, such as English (Chomsky & Halle 1968, Prince & Smolensky 1993/2004), learning a different Weight-to-Stress rule might seem to be fairly straightforward, although it might prove more difficult than expected because of language transfer effects (Edward & Zampini, 2008; Hancin-Bhatt, 2008). On the other hand, for speakers of a language with fixed stress, such as French (Dell 1980), learning any of the stress rules might prove to be difficult, due in part to a general difficulty in perceiving stress, a phenomenon referred to as stress 'deafness' (Dupoux, Pallier, Sebastián-Gallés, & Mehler, 1997; Peperkamp & Dupoux, 2002). The effect of stress 'deafness' will be further discussed in sections 2.4 and 3.3.1.

2 Theoretical background

Under an Optimality Theoretic framework, a natural pattern is derived from one or more permutations of cross-linguistically licit constraints while an unnatural one is not based on constraints that are grounded in universal linguistic principles of phonology. A phonological principle of naturalness can also be grounded in one or more phonetic factors. For example, heavy syllables are often longer in duration and have greater acoustic energy than light syllables (Gordon, 2004). However, stress can also occur on light syllables, based on a combination of language-specific factors. This variability demonstrates that stress determination is not fully dependent on such phonetic factors such as length and energy. Thus, as a phonological distinction, stress can be based on a phonetic reality, but it can also be based on other linguistic distinctions such as syllable structure, sonority and edge prominence (Gordon, 2002; Prince & Smolensky, 1993/2004). So while there might be a phonetic rationale for the natural phonological rule of stressed syllables being heavy, given that heavy syllables are often greater in duration and perceptual energy, the unnatural version, in which stress is attracted to light syllables, is not entirely unnatural phonetically. Many languages, including English and Spanish, have stress on light syllables. However, there are no known languages that will stress light syllables but not stress heavy syllables when the language has both heavy and light syllables.

2.1 Weight-to-Stress principle

Syllable weight is a common basis for stress attraction in the world's languages. Languages that use a syllable weight distinction in stress assignment vary as to what types of syllable structures comprise heavy syllables. They can be CVV, CV:, CVC, CVVC etc. (Hayes, 1995). For example, both CVC and CVV syllables are heavy in Latin (Hayes, 1995) and Hindi (Kelkar, 1968). But in Khalka, CVV syllables are heavy but CVC are not (Gordon, 2002; Hyman, 1985/2003). Cairene Arabic has superheavy CVCC or CVVC syllables (Hayes, 1995). Light syllables are usually open, typically CV syllables. This heavy/light weight distinction is an interesting one to study because while there are numerous examples of stress being attracted to heavy syllables cross-linguistically, there are no examples of languages where stress prefers light syllables over heavy ones, as a general rule, all else being equal (Hayes, 1995, Hyman 1985). Of course, in language all else is never equal because real languages often have various stress rules that may interact and obscure the generalization of weight attracting stress. For example, stress rules in English are quite complex and interact to result in stress occurring on both heavy syllables, such as ˈ*bungalow* [[ˈbʌŋ.gə.lo], *e*ˈ*ternal* [ə.ˈtəɹ.nəl], and *po*ˈ*lice* [pə.ˈlis] and light ones, such as ˈ*Africa* [ˈæ.frɨ.ka] and ˈ*cinema* [ˈsɪ.nə.ma]. While the principle of stress being attracted to heavy syllables can be incorporated into a grammar under various theoretical methods (Burzio, 1994; Hayes, 1982, 1995), I will focus on an Optimality Theoretic approach to briefly explain the stress grammar of the participants' native languages, English and French. In Optimality Theory (OT) the Weight-to-Stress (WSP) constraint captures the generalization of heavy syllables attracting stress through use of a violable constraint requiring that heavy syllables be stressed.

1) WSP
   Stressed syllables are heavy

Quantity-sensitive languages like English use the WSP to rule out stress occurring on light syllables in certain word positions. Primary stress in English is variable, that is, it can occur on one of any number of different syllables in a multisyllabic word. For nouns, stress can be expressed on a heavy penultimate syllable, such *a*ˈ*ddendum* [ə.ˈdɛn.dʌm], or in the case where the penultimate syllable is light, on the antepenult, as in ˈ*amethyst* [ˈæ.mə.θɪst]. While main stress usually occurs on one of the final three syllables of the word, in some exceptional cases where there is secondary stress later in the word, primary stress can be expressed even earlier through stress retraction, as in ˈ*catama*ˌ*ran* [ˈkæ.ɾə.mə.ˌɹæn] and ˈ*anec*ˌ*dote* [ˈæ.nək.ˌdot]. There are several possible approaches to analyzing English stress, some of which appeal to the direct role of a WSP constraint, (Hammond, 1999; Pater, 2000; Prince & Smolensky, 1993/2004) and others that do not (Burzio, 1994). While these analyses differ in the details, there is general agreement that syllable weight influences stress assignment in English (Burzio, 1994; Hammond, 1999; Hayes, 1982, 1995; Pater, 2000). While a complete analysis of English stress is beyond the scope of this paper, the general pattern of stress exhibits the influence of an ALIGN-RIGHT constraint to account for foot assignment going from right to left. ALIGN-RIGHT dominates ALIGN-LEFT.

2) ALIGN-RIGHT (HEAD, PRWD)
   The right edge of the head foot of the Prosodic Word must coincide with the right edge of the Prosodic Word.

3) ALIGN-LEFT (HEAD, PRWD)
   The left edge of the head foot of the Prosodic Word must coincide with the left edge of the Prosodic Word.

The ranking hierarchy of ALIGN-RIGHT >> ALIGN-LEFT accounts for stress being largely confined to the final three syllables of the word. The invariable trochaic meter in English gives evidence that TROCHEE (which demands that feet be left-headed) is undominated. In addition, NONFINALITY (the head of the prosodic word must not be final in the prosodic word) and the WSP are ranked in such a way as to, in general, repel stress from final syllables while attracting them to a heavy syllable, for example, *A*ˈ*manda* [ə.ˈmæn.də] (cf. *ˈ*Amanda* [ˈa.mæn.də]).

French, on the other hand, is not quantity-sensitive (Dell, 1980; Gordon, 2002). That is, stress placement is not dependent on syllable weight, but, rather, is fixed on the final full vowel of the word or phrase, as in *domesˈtique* 'servant' [do.mes.ˈtik] and *panoraˈma* 'panorama' [pa.no.ra.ˈma] (Dell, 1984; Hayes, 1995; Jun & Fougeron, 2000; Picard, 1987). Some (e.g. Jun & Fougeron, 2000) argue that stress in French occurs at the phrase level and not the word level. While this is an interesting analysis, it does not affect these experiments as most agree that stress in French is fixed. Word- or phrase-final stress in French occurs regardless of the weight of the final stressed syllable. French stress thus shows that ALIGN RIGHT >> ALIGN LEFT since stress invariably occurs on the final syllable with a full vowel, whether that syllable is heavy or light. Thus a principle of syllable weight attracting stress does not influence stress assignment in French; rather French stress is determined by syllable position. The WSP is low-ranked and never exerts any influence on where stress lands. Table 1 summarizes the difference between English and French with respect to the pertinent stress factors.

Table 1 Summary of English and French stress

Stress Factors	English	French
Meter	Trochaic	Iambic
Stress position	Variable with a preference for non-final syllables	Fixed on the final full vowel
Quantity-sensitive	Yes (WSP is active)	No (WSP is not active)

2.2 The experimental Stress Heavy and Stress Light languages

The natural rule in the artificial languages designed for the experiments follows an observed pattern where primary stress is on the leftmost heavy syllable, else leftmost. That is, stress occurs on the first heavy (CVC) syllable (for example, ˈtuf.da.tatʃ, gu.ˈbaʃ.tu and ku.di.ˈbuʃ) but if all the syllables are light or all the syllables are heavy (as in ˈku.pi.ba and ˈpaf.butʃ.tif), then the first syllable in the word is stressed. I will refer to this as the Stress Heavy rule. This pattern is similar to Amele (Madang Province, Papua New Guinea) (Roberts, 1987) and the now-extinct Californian language Yana (Sapir & Swadesh, 1960). In Amele, for example, monomorphemic words are stressed on the first heavy (CVC or CVV) syllable, otherwise on the first syllable.

(4) Amele stress (Roberts 1987)
Stress leftmost heavy
a. [jæ.ˈwæl.ti] 'wind from north'
[ˈmɛʊ.lə] 'right (hand)'
[ˈtug͡b.dɔʔ] 'to butcher'
[ʔɔ.ˈluʔ] 'forest'

b. Otherwise, stress initial syllable
[ˈnu.i] 'island'
[ˈɛ.ge] 'we'
[ˈnɪ.fu.lə] 'species of beetle'

The unnatural version of the Stress Heavy rule is the opposite of the natural: stress the leftmost light syllable, else leftmost. That is, stress regularly occurs on the first CV syllable regardless of position in the word (for example, ˈki.titʃ.da, kif.ˈpa.du and paʃ.guʃ.ˈtu), but if all syllables in the word are light or if all the syllables are heavy then stress is on the initial syllable (such as ˈku.pi.ba and ˈbiʃ.kuf.patʃ). This is the Stress Light rule.

2.3 Analysis of the Stress Heavy and Stress Light artificial languages

This section provides the OT analysis of the natural Stress Heavy and unnatural Stress Light stress rules demonstrating that while the rules are formally equal, the constraints for the natural and unnatural conditions differ. For both the natural and unnatural stress rules ALIGN-LEFT ensures that stress occurs on the leftmost syllable. The constraint ranking that chooses a stressed heavy syllable over a stressed light one is: WSP >> ALIGN-LEFT.

(5) WSP >> ALIGN-LEFT

/gapuftiʃ/	WSP	ALIGN-LEFT
☞a. ga.ˈpuf.tiʃ		*
b. ˈga.puf.tiʃ	*!	
c. ga.puf.ˈtiʃ		**!

Candidate b violates the high-ranking WSP and candidate c loses because by incurring two violations of ALIGN-LEFT it is harmonically bounded by candidate a. Since the default stress pattern calls for stress on the leftmost and not the rightmost syllable, ALIGN-LEFT >> ALIGN-RIGHT. This pattern differs from that of both English and French.

(6) WSP >> ALIGN-LEFT >> ALIGN-RIGHT

/kadʒtifpaʃ/	WSP	ALIGN-LEFT	ALIGN-RIGHT
☞ a. ˈkadʒ .tif.paʃ			**
b. kadʒ.ˈtif.paʃ		*!	*
c. kadʒ.tif.ˈpaʃ		*!*	
/bukadi/			
☞ d. ˈbu.ka.di	*		**
e. bu.ˈka.di	*	*!	*
f. bu.ka.ˈdi	*	*!*	

In cases where the target word is composed of all light syllables, stress still emerges on the initial syllable, candidate d, since high-ranked WSP is violated by all of the candidates equally and is thus not the deciding constraint. The final ranking that obtains the Stress Heavy language is WSP >> ALIGN-HEAD LEFT >> ALIGN-HEAD RIGHT.

For the unnatural Stress Light version, where stress is on the leftmost light syllable, else leftmost, a different kind of constraint must be proposed. To produce an output that fulfills this phonological rule the learner might hypothesize that there is a constraint that prefers stress on light syllables over heavy ones. Let's call this the ANTI-WSP constraint.

(7) ANTI-WSP (hypothetical)
Stressed syllables are light

If ANTI-WSP dominates ALIGN-HEAD LEFT, then when ALIGN-HEAD LEFT is violated by a candidate with an initial heavy syllable the choice will fall on the word with stress on the leftmost light syllable.

(8) ANTI-WSP >> ALIGN-HEAD LEFT produces stress on the light syllable over the heavy.

/kaʤtifba/	ANTI-WSP	ALIGN- LEFT
☞a. kaʤ.tif.ˈba		**
b. ˈkaʤ.tif.ba	*!	
c. kaʤ.ˈtif.ba	*!	*

ANTI-WSP ranked over ALIGN-LEFT produces stress on light syllables, as in candidate a. The proposed ANTI-WSP rules out candidate b and candidate c is harmonically bound by candidate a and is thus ruled out.

The theoretical existence of a WSP constraint is supported by ample cases of languages in which stress is attracted to heavy syllables. However, the literature provides no examples of stress being attracted to light syllables over heavy syllables, all other factors being equal. This absence indicates that an ANTI-WSP constraint does not exist. I suggest that learning an unfamiliar rule where stress is attracted to heavy syllables is a task that is facilitated by the domain-specific language mechanism, in which such tacit knowledge lies. This tacit knowledge is instantiated through the universal presence of the WSP constraint in CON. The Stress Light rule, on the other hand, is not helped by the domain-specific mechanism as it goes counter to the WSP. Trying to do a linguistic task that is not based on natural linguistic principles presents a conflict to the learner. One can imagine that the built-in bias of the linguistic system expects heavy syllables to be stressed, yet the learner's input presents stress on light syllables, even when heavy syllables are present. The effort to reconcile the difference between expectation and reality results in increased difficulty in the task, which slows learning. Further, the proposed constraint ANTI-WSP is a spurious constraint, having no epistemic grounding in natural language phenomena. How then does the learner acquire the Stress Light rule? They would have to rely on general, nonlinguistic pattern induction extracted from the input in order to acquire the unnatural stress rule (Hayes et al., 2009; Kawahara, 2008). Relying on general pattern induction, which is part of a general cognitive mechanism, will allow the learning of the unnatural rule, but at a cost. The cost is that learning the unnatural rule will be more difficult than learning the natural version. If that cost is demonstrated by learners of the Stress Light rule, then there will be some evidence that the general cognitive mechanism alone cannot account for all of language learning (Bybee, 2006; Christiansen & Chater, 2008). The experiment includes learning a set of words designed to familiarize participants with the underlying stress pattern of their respective target language, Stress Heavy or Stress Light. Learning these words requires use of the general cognitive mechanism, which should enable both the Stress Heavy and the Stress Light groups to learn their familiarization words equally well since that task is based on memorization of the audio and visual stimuli.

2.4 Research questions and predictions

As discussed in section 2.1, English has a variable stress system in which stress occurs in a systematic fashion on any of several syllables and the WSP plays a part in choosing the stressed syllable. On the other hand, French has fixed stress that is consistently predictable on the final full vowel in a syllable and the WSP plays no role in choosing stress location. Thus this research is designed to answer two questions. First, is it easier to learn a natural rule where heavy syllables are stressed than an unnatural one where light syllables are stressed? Based on previous findings such as those described in the introduction (e.g. Moreton 2008, Pater & Tessier 2005, Zhang & Lai 2010) as well as similar research involving French and English speakers learning a different natural and unnatural stress system (Carpenter, 2010), the prediction is that both English and French speakers will learn the natural stress rule better than the unnatural. Second, will native speakers of a variable stress language with a syllable weight distinction perform differently from speakers of a fixed stress language with no syllable weight distinction? ALIGN RIGHT dominates ALIGN LEFT in both French and English. However, English has additional constraints including the WSP, NONFINALITY and the undominated TROCHEE, which work together to produce its complex stress pattern. From an OT perspective, there is no *a priori* reason to know if there is a difference between re-ranking constraints that produce variable stress or fixed stress. Carpenter (2010), in a study comparing English and French performance in learning stress based on vowel height, found that English participants were more accurate than French. The prediction, then, is that English speakers will learn both the natural and unnatural versions better than French speakers. The idea behind this assumption is that English already has variable stress, which might provide English speakers with more facility in assigning stress on different syllables, and French does not.

French speakers are disadvantaged in an additional way. Previous research has shown that French speakers have difficulty identifying stressed syllables within a word, sometimes referred to as 'stress deafness' (Carpenter, 2010; Dupoux, et al., 1997; Peperkamp, Dupoux, & Sebastián-Gallés, 1999). Dupoux et al. (1997) argued that stress 'deafness' increases the cognitive processing load of speakers, which most likely prevents them from encoding stress as part of their mental representation of the word. This effect of stress 'deafness' is likely to reduce accuracy among the French participants. Thus French speakers need to be trained to pick out stressed syllables reliably. This special training will be described in the Methods section below.

In order to learn the unnatural Stress Light rule, both French and English speakers are faced with the same task, to posit an unnatural Anti-WSP constraint. It is possible that English learners will have an advantage over French learners by virtue of the fact that the target language has variable stress, as does their native language, while French learners might have difficulty overcoming their fixed stress system to learn a variable one.

In summary, the following are the predictions for learning the Stress Heavy and Stress Light languages as seen in scores on the novel words are:
1. The natural group (all participants) will perform better than the unnatural group
2. English speakers will score better than the French on both artificial languages

3 The experiment

3.1 Participants

There were a total of 80 participants, 40 English and 40 French, of whom 20 were in the Stress Heavy group and 20 in the Stress Light group for both English and French. Of the original 52 English participants, one was omitted for not meeting the criterion of getting at least two-thirds (67%) correct on the pretraining words (that is, they could not reliably identify stressed syllables in general) and eleven were omitted for failing the 67% criterion on the familiarization words. Of the eleven omitted, two were in the Stress Heavy group and nine in Stress Light. There were a total of 58 French participants of whom ten did not pass the criterion of getting at least 67% correct on the pretraining words and eight were omitted for failing the criterion of 67% correct on the familiarization words. Of the eight participants who did not pass the familiarization criterion, three were in the Stress Heavy group and five in Stress Light. The failure rate for French speakers was higher than that of English speakers.

All participants were native speakers of either English or French and data was gathered in Massachusetts, USA and Paris, France. English participants were college students and residents of Massachusetts and recruited through online flyers and word-of-mouth. French participants were recruited by means of flyers at Paris III (Sorbonne Nouvelle) and Paris V (Rene Descartes) universities. Other participants were obtained through online recruitment on the RISC (Relais d'information sur les sciences de la cognition) website. French participants were 18 to 37 years of age, M = 21.61 (SD = 5.23) and English participants were 18 to 36 years of age, M = 20.88 (SD = 3.67). None of the participants reported having hearing problems or being bilingual, although several had studied a foreign language.

3.2 Stimuli

3.2.1 Creating the syllables

The stimulus set consisted of heavy CVC and light CV syllables. Heavy syllables were formed by combining voiced and voiceless stop onsets, [b, d, g, p, t, k] with the vowels, [a, i, u] and closed with [f, ʃ, ʤ, ʧ] as codas. Although these affricates do not occur as codas in French, the syllables were rated by two native French speakers as being audibly perceptible. Stop onsets were chosen for their ease of perception of both voiced and voiceless counterparts (Cole & Scott, 1974). Codas were selected from the natural classes of fricatives and affricates to maximize perceptibility (Harris, 1958). Light syllables were formed by combining the six voiced and voiceless stops with the tense vowels [a, i, u]. Thus the feature that distinguishes between the heavy and light syllables is that the heavy syllables have a coda and the light syllables do not.

The target syllables were recorded by a trained female phonetician whose native language is American English. Each syllable was embedded in a carrier sentence where they received uniform stress. The syllables were within the carrier sentence "I wanna _____ twice." The carrier was chosen in order to easily separate the target syllables from the surrounding speech. Beginning the word following the target syllable with a stop allowed for easy identification of the end of the waveform to be excised. Individual CV and CVC syllables were cut out of the carrier phrases and subsequent manipulations were made using Praat (Boersma & Weenink, 2010). Care was taken to cut syllables consistently so as to include all of the syllable coda, or nucleus in the case of CV syllables, and none of the following word onset of the carrier phrase.

A total of 72 different heavy syllables and 18 light syllables were recorded. Of those, 61 heavy syllables and 17 light syllables were used in creating the words. Omitted syllables were either not good exemplars or had sound degradation that precluded them from being a part of the final syllable set. The syllables used are listed in (9). The vowels for all syllables are tense.

(9) Syllables used for both natural and unnatural versions

Light syllables
ba, bi, bu, da, di, du, ga, gu, ka, ki, ku, pa, pi, pu, ta, ti, tu
Heavy syllables
baf, baʃ, baʤ, baʧ, bif, biʃ, biʤ, biʧ, buf, buʃ, buʧ, daʤ, dif, diʃ, diʤ, duf, duʃ, duʤ, duʧ, gaʃ, gaʤ, gaʧ, giʃ, giʧ, guf, guʃ, guʤ, guʧ, kaf, kaʃ, kaʤ, kaʧ, kif, kiʃ, kiʤ, kiʧ, kuf, kuʃ, kuʤ, kuʧ, paf, paʃ, paʤ, paʧ, pif, piʤ, piʧ, puf, puʃ, puʤ, puʧ, taʤ, taʧ, tif, tiʃ, tiʤ, tiʧ, tuf, tuʃ, tuʤ, tuʧ

To construct the experimental words, each syllable was manipulated in Praat in the following ways. First, 25 milliseconds of silence was affixed to the beginning of each syllable to aid in the detection of each syllable once they were concatenated into words. Without this very brief insertion of silence, the syllables run into each other, making perception of the individual syllables in the words difficult. Next, a series of adjustments and manipulations were made in duration, pitch, and amplitude to create the stressed syllables. Previous research has shown that increased duration, pitch and amplitude add to the perception of stress (Fry, 1955; Jassem, Morton, & Steffen-Batog, 1968). To maximize the perception of stressed syllables without distorting the sound, the amplitude of each stressed syllable was first equalized to 70 dB then increased by 20%. The duration of each stressed syllable was increased by 20% and its pitch increased by 20% as well. Because an earlier pilot study showed that pitch contours helped English listeners to more reliably identify stressed syllables in nonsense words, a pitch contour was overlaid to create three stressed versions: initial, medial, and final, based on the position of the stressed syllable in the word. By this procedure syllables in initial stress position received a falling contour, syllables in medial stress position received a rising then falling contour and final stressed syllables had a rising contour. The syllables were then resynthesized in Praat using the Pitch Synchronous Overlap Add (PSOLA) algorithm. Independent raters judged the syllables to be perceptible as stressed syllables.

A measurement of the durations of the CV stressed syllables revealed that the Ci syllables were significantly longer than Ca and Cu. To avoid giving one set of syllables an advantage in perceptibility, the stressed CV syllables were equalized for duration by syllable group, thus keeping the natural variation that occurs with different onsets. Durational adjustments were made only to stressed syllables. To do this I first measured the durations of the vowels in each syllable by syllable group, for example, [bu], [du], [gu], [ku], [pu], [tu], then calculated an average vowel length of that set of syllables. Average vowel durations were obtained for the syllable groups, [a], [i], and [u]. Then a grand average (average of the averages) was calculated, which then was the target average for the syllable groups. Calculating the difference between the grand average and the syllable group's average gave the percentage to increase the

[a] syllables and decrease the [i] syllables. Thus [a] syllables were increased by 3.6% and [i] syllables were decreased by 3.5%. No adjustments were needed to [u] syllables as their durations were less than 5 ms. different from the grand average, which is well below the just noticeable difference of 25 ms. for perception of vowel length differences (Klatt, 1976).

Unstressed syllables were produced by reducing the intensity of the original recorded syllables by 6 dB. These adjustments maximized the perceptual difference between stressed and unstressed syllables. Table 2 summarizes the average measurements for unstressed and their stressed versions after manipulations were made.

Table 2 Average measurements of syllables

Syllable Type	Syllable Structure	N	Duration msec (SD)	Intensity dB (SD)	Pitch Hz (SD)	Energy - Pa^2sec (SD)
Unstressed	CV	17	357 (40)	69.70 (.05)	187.98 (17.59)	.0013 (.0002)
	CVC	61	434 (46)	69.54 (.31)	204.07 (28.51)	.0016 (.0001)
Average Unstressed		78	417 (55)	69.57 (.28)	200.56 (27.25)	.0015 (.0002)
Stressed	CV	51	417 (42)	75.91 (.23)	213.81 (18.51)	.0065 (.0008)
	CVC	183	491 (55)	75.88 (.21)	239.58 (34.10)	.0073 (.0009)
Average Stressed		234	475 (60)	75.89 (.21)	233.96 (33.10)	.0074 (.0010)

Measurements of the syllables showed that the stressed syllables averaged 475 msec in length and the unstressed ones, 417 msec. This difference was significant by an independent samples t-test, $t(310) = -7.43$, $p < .001$. The other measures, not assuming equal variances, also showed a significant difference between unstressed and stressed syllables: Intensity, with means averaging 70 and 76 dB respectively for unstressed and stressed syllables, ($t(182.982) = -109.175$, $p < .001$; pitch (unstressed 204 hertz, stressed 234 hertz), $t(158.687) = -8.864$, $p < .001$; perceptual energy (unstressed .0015 Pa^2sec, stressed .0074 Pa^2sec), $t(286.789) = 86.509$, $p < .001$). Perceptual energy is a correlate of stressed syllables (Gordon, 2002) and is a factor of syllable duration and intensity. The definition is: $\int x^2(t)\, dt$ where x(t) is the amplitude of the sound at time t and d is duration. So overall, the stressed CV and CVC syllables' greater duration (Fry, 1958) and energy should add to their prominence in relationship to the unstressed syllables (Gordon, 1999, 2002). Specifically, in a three-syllable word with one stressed and two unstressed syllables, the stressed syllable, CV or CVC, was more prominent than the unstressed ones.

3.2.2 Creating the words

The manipulated heavy and light syllables were concatenated to form three-syllable nonsense words, 28 familiarization words and 66 novel words. The full complement of syllables was distributed over all the words so heavy syllables were used an average of 2-3 times, and light syllables an average of 7 times each.

A combination of heavy (H) and light (L) syllables created word types of different syllable patterns: HHH, HHL, HLL, HLH, LLL, LHL, LHH, and LLH. Given the overall stress rule for both languages, these eight syllable patterns would produce initial stress on words of five different syllable patterns or 62.5% of the words, medial stress on words of two of the patterns or 25%, and final stress on just one syllable pattern, 12.5%. However, in order to give the learners sufficient exposure to correct words with non-initial stress, this distribution was changed so that 50% had first syllable stress, 25% had second syllable stress and 25% had third syllable stress. This distribution of the word types means that 50% of the training tokens were consistent with the default "stress left" pattern, while the other 50% required reference to syllable weight. These percentages were achieved by adjusting the number of tokens (words) of each syllable shape. Table 3 gives the distribution of training and testing words by stressed position and syllable shape.

Table 3 Distribution of word shapes and stress patterns

Natural - Stress Heavy				Unnatural - Stress Light		
Stress Type	**Word Shape**	**#Tokens Training**	**# Tokens Testing**	**Word Shape**	**# Tokens Training**	**# Tokens Testing**
Initial	ˈHHH	2	4	ˈLLL	2	4
	ˈLLL	3	5	ˈHHH	3	4
	ˈHLL	3	4	ˈLHH	3	4
	ˈHLH	3	4	ˈLHL	3	5
	ˈHHL	3	5	ˈLLH	3	5
Total Initial		14 (50%)	22 (33%)		14 (50%)	22 (33%)
Medial	LˈHH	4	10	HˈLL	4	11
	LˈHL	3	12	HˈLH	3	11
Total Medial		7 (25%)	22 (33%)		7 (25%)	22 (33%)
Final	LLˈH	7 (25%)	22 (33%)	HHˈL	7 (25%)	22 (33%)
Total words		28	66		28	66

All the words were rated as intelligible by native French and English speakers.

3.3 Methods and Procedure

3.3.1 French ‘stress deafness’

To fully understand the methods and procedures, I will first discuss French stress ‘deafness’ as it affected the experimental design.

A significant issue that arises in teaching French speakers a stress rule is the fact that French speakers have difficulty recalling stress positions. This phenomenon, sometimes referred to as ‘stress deafness’, has been a relatively robust finding in the perception literature (Dupoux et al., 1997, Peperkamp et al., 1999, Peperkamp and Dupoux, 2002). However, ‘stress deafness’ can be overcome, at least temporarily, by a gradual training process that improves learners’ ability to reliably pick out the stressed syllable in a multisyllabic word (Carpenter, 2015) The training process exploits a stress cue that French speakers already associate with prominence, that is, duration (DeLattre, 1966; O’Shaughnessy, 1984).

Three sets of three-syllable stimulus words were created with the stressed syllable in each word having exaggerated duration in addition to the pitch and intensity manipulations described in section 3.2.1. Words were made up of a combinatioin of CV and CVC syllables, such as *bigafda* [bi.gaf.da] and *tuʃbadif* [tuʃ.ba.dif]. The first set of words increased the stressed syllable to 180% of the originally recorded length; the second set of words had stressed syllables of 150% duration and the final set had stressed syllables of 120% duration. Pilot testing had previously shown that French speakers could accurately identify stressed syllables at the 180% duration. So starting from that increased length, the training to improve perception presented the words with the longest durations first, then participants were stepped down to the 150% durations and finally they were presented with words where the stressed syllables were of 120% duration. Since the stressed syllables in the main experiment also had durations of 120% of the original syllables, the training was designed to get French speakers to perceive those syllables as being stressed.

3.3.2 Method

There were three parts to the experiment: an initial pre-training identification task to ensure that participants could accurately identify stressed syllables in multisyllabic words; a training task to familiarize participants with the target stress pattern, either Stress Heavy or Stress Light; and a test with novel words similar to the familiarization words. Participants were first given background information on what a stressed syllable is. Specifically they were told by the researcher that stress can be described as the part of the word that sounds more prominent than the other parts. Research in second language acquisition has shown that explicit instruction can facilitate learning, which was the intention (de Graaff, 1997). Then the researcher informed them that they were going to learn words in an unfamiliar language, which would be followed by tests to see how well they had learned that language. Exact instructions are included in Appendix A. They were then randomly assigned to either the Stress Heavy language or the Stress Light language group. Each participant sat at a computer station, donned Bose Quiet Comfort ® 15 Acoustic Noise Cancelling ® headphones and was told to follow the instructions on the computer screen to proceed through the experiment. All instructions were built into the program, SuperLab Pro 4.5, which also recorded subjects' responses.

3.3.3 Pre-training task

Participants were first presented with a pre-training task. French participants were given the stress 'deafness' identification task described above in section 3.3.1. In this task they had to press a key labeled 1, 2, or 3 to identify if stress occurred on the first, second, or third syllable of each nonsense word. English participants performed an AXB task in which they heard groups of three nonsense words where the stressed syllable in word X matched either the stress in word A or word B. Subjects had to indicate whether the first two words had the same stressed syllable or if the matching stress was demonstrated by the second pair. During the first 10 trials, the word triads were the same segmentally, only differing in stress location, such as, *ˈdapiki* – *ˈdapiki* – *dapiˈki*. In the remaining 20 trials the groups of words presented in the AXB format were all different segmentally so subjects had to choose the matching pair solely on the basis of the stressed syllable, such as *guˈpagadu* – *kæˈsugaza* – *puzibiˈtæ*. They pressed either 1 or 2 to indicate whether the first two words or the second two words had stress on the same syllable. All participants, French and English, had to get at least 67% correct on their respective tasks in order to be included in the main experiment.

3.3.4 Training task

In the main experiment participants heard groups of four familiarization words, randomly repeated four times each, and then were tested on how well they could identify the correctly stressed words that they had just heard. Each audio familiarization word was accompanied by a photographic image of real life items such as a bicycle, a mask, a tire, etc. from Big Box of Art 350,000 (Hemera Technologies, 2001). The same word-picture pairing was used for all participants within the target language group. There was no connection between the word and the accompanying picture, that is, words for the items did not sound like the nonsense words being used to represent those items. Participants were given the impression that they were learning the lexical names of these objects in a different language. The words were presented aurally, not in written form, that is, they were not spelled out on the screen. The sound lasted for the length of time it took to say each word and the picture stayed on the screen for 1500 msec.

After being exposed to a group of four words, the participants were tested on those words in a two-alternative forced choice task. In a two-alternative forced choice (2AFC) task participants are presented with two versions of a stimulus, in this case, stress on different syllables of the same word, and must choose which version is correct. For example, participants in the Stress Heavy group heard a correct and an incorrect version of a nonsense word, such as *pibiˈtadʒ* [pi.bi.ˈtadʒ] and *piˈbitadʒ* [pi.ˈbi.tadʒ] and then had to choose which version was correct. The correct and incorrect versions were counterbalanced throughout the experiment.

Participants pressed 1 if the first word was correct or 2 if the second word was correct. The numerals “1” and “2” were superimposed over the “z” and “/” keys to allow maximum distance between the choices, thus decreasing the chance of participants hitting the wrong key accidentally. The experiment did not move forward until the participant had made a choice. After making a choice, participants received feedback in the form the following statement, “The correct response is:” printed on the computer monitor while they heard the correct version of the word. Feedback did not include the photographic image and lasted for at least 750 msec or until the audio word was finished playing. After learning 16 familiarization words and again after learning the remaining 12 familiarization words, participants were presented with novel words, again as a 2AFC task, and they had to choose the correctly stressed novel word. There was 1000 msec. between the audio presentation of the first and second choices. After presenting the second choice the experiment did not move forward until the participant pressed a key to continue. They received no feedback with the novel words and these words had no accompanying picture. The purpose of having two sets of novel words was to see how well participants had begun to internalize the stress pattern part way through the training as compared to after the complete training. It was anticipated that they would perform better on the second set than on the first.

Table 4 details the step-by-step procedure of the experiment, with an explanation of the steps following.

Table 4 Familiarization and Testing Method

a.	Pre-training	Participants perform AXB task (English) or identification task (French) and reach criterion (67% correct answers).
	Main Experiment	
b.	Familiarization Block 1 Words 1-4	Participants listen to 4 familiarization words randomly repeated 4 times each, with an accompanying photographic image.
c.	Testing Block 1 Words 1-4	Participants given 2AFC test on the 4 words they just heard. They receive feedback.
d.	Familiarization Block 2 Words 5-8	Subjects hear 4 new familiarization words randomly repeated 4 times each, with an accompanying photographic image.
e.	Testing Block 2 Words 5-8	Participants given 2AFC test on the 4 words they just heard. They receive feedback.
f.	Review Words 1-8	Participants listen to the first 8 words with their accompanying photograph, repeated randomly twice.
g.	Testing Block 3 Words 1-8	Participants are tested on the first 8 words. They receive feedback as to the correct answers.
h.	Familiarization /Testing Blocks 4 and 5 Words 9-12 and 13-16	Same as blocks 1 and 2 above. Each training block presents new words.
i.	Review Words 9-16	Participants listen to the second 8 words with their accompanying photograph, repeated randomly twice.
j.	Testing Words 9-16	Participants are tested on the second 8 words. They receive feedback as to the correct answers.
j.	Review Words 1-16	Participants listen to the first 16 words with their accompanying photograph, repeated randomly twice.
k.	Testing Words 1-16	Participants are tested on the first 16 words. They receive feedback.
l.	Novel Test 1	Participants presented with 18 novel words consistent with the patterns they have been learning. They receive no feedback.
m.	Familiarization /Testing Blocks 7, 8, and 9 Words 17-20, 21-24, 25-28	Same as Blocks 1 and 2 above. Each training block presents new words.
n.	Review 17-28	Participants listen to the last 12 words with their accompanying photograph, repeated randomly twice.
	Testing Words 17-28	Participants are tested on the last 12 words. They receive feedback as to the correct answers.
o.	Review 1-28	Participants listen to all 28 words with their accompanying photograph, repeated randomly twice.
p.	Testing Words 1-28	Participants tested on all 28 words learned, with feedback.
q.	Novel Test 2	Participants tested on 48 novel words, no feedback.

To compile the data, correct and incorrect answers were converted to the numerical values of 1 and 0 respectively. The data was input into SPSS v. 21.0 for analysis of subjects' performance on the novel words.

4 Results

Responses were analyzed in SPSS using a binomial logistic regression model where the dependent variable was the probability of choosing the correctly stressed word given a binary choice. The independent variables were the target language, Stress Heavy or Stress Light, and the native language, English or French. Target languages were coded with 0 for Stress Light and 1 for Stress Heavy. Native language was also binary with French coded 0 and English coded 1. In interpreting the results tables, note that the reference categories are the variables coded as 1, that is, Stress Heavy for target Language and English for native language. This means that negative betas indicate that performance on the variable coded as 0 is significantly worse than the reference variable. First there will be a description of the combined results of all participants followed by details of the English and French results.

4.1 All participants

All scores for the familiarization and novel words are provided in Table 5.

Table 5. Scores for familiarization and novel words for Stress Heavy and Stress Light

Words	Target Language	English % Correct (SD)	French % Correct (SD)	Total % Correct (SD)
Familiarization	Stress Heavy	82.86 (9.60)	82.14 (9.49)	82.50 (9.43)
	Stress Light	84.29 (10.96)	82.28 (12.47)	83.28 (11.63)
Novel 1	Stress Heavy	60.56 (13.71)	57.22 (15.65)	58.89 (14.60)
	Stress Light	62.22 (13.64)	53.06 (14.97)	57.64 (14.86)
Novel 2	Stress Heavy	62.19 (12.84)	56.46 (17.01)	59.27 (9.74)
	Stress Light	55.83 (15.96	53.54 (13.00)	54.37 (7.89)
All novel words	Stress Heavy	61.74 (12.99)	56.67 (16.53)	59.20 (15.03)
	Stress Light	57.58 (15.52)	53.41 (13.45)	55.49 (14.62)

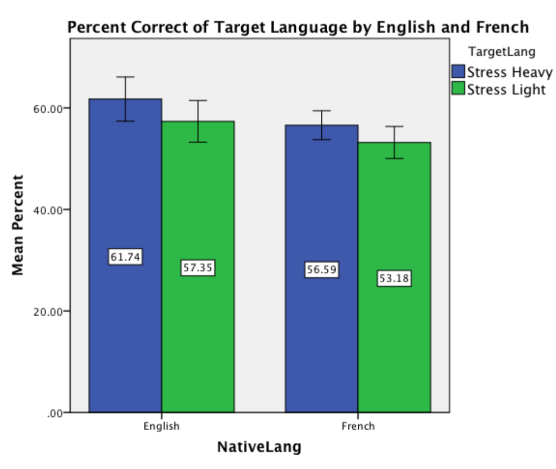

Figure 1 Percent scores of English and French performance on the Stress Heavy and Stress Light languages

French and English participants performed equally well on the familiarization words with an average of 83% correct for both target languages. A binomial logistic regression analysis shows no significant difference between the probability of choosing the correct stress by target language, (β = 1.002E-013, SE = .0817, p = 1.00, or by native language, β = .013, SE = .0816, p = .870). The results indicate that there was no difference in accuracy between the English and French in learning the familiarization words of the Stress Heavy and Stress Light languages.

4.1.1 All participants – accuracy on the novel words

Accurate responses on the novel words is an indication of how well participants have learned the underlying stress pattern, as opposed to perhaps memorizing the familiarization words. The first set of novel words, consisting of 18 words, was presented after participants were exposed to 16 familiarization words and the second set, 48 words, was presented after participants had learned all 28 familiarization words.

A binomial logistic regression analysis was done on the novel words, with probability of choosing the correct stress as the dependent variable, and target language (Stress Light = 0 and Stress Heavy = 1) and novel order (first set of novel words = 1 and second set of novel words = 2) as factors.

Table 6 Logistic Regression comparing accuracy based on novel word order

Variable	β	Std. Error	Wald Chi-Square	df	p
(Intercept)	.377	.047	65.966	1	.000
Target Language	-.189	.065	8.410	1	.004
Novel Order	-.018	.089	.041	1	.840
Target * Novel Order	.138	.125	1.212	1	.271

There was no significant difference between the scores on the two sets of novel words as a whole, *p* = .840, as can be seen in Table 6, thus the scores for both sets have been combined in the analyses to follow.

In the binomial logistic regression analysis of all the novel words, the dependent variable was the probability of choosing the correct word and fixed factors were Target Language (Stress Heavy or Stress Light) and Native Language (English or French). Target Languages was coded with 0 for Stress Light and 1 for Stress Heavy. Native Language was also binary with French coded 0 and English coded 1. The reference categories are Stress High for target language and English for native language.

Table 7 Logistic Regression of novel words – all participants

Variable	β	Std. Error	Wald Chi-Square	df	p
(Intercept)	.479	.057	71.429	1	.000
Target Language	-.183	.078	5.286	1	.022
Native Language	-.213	.079	7.242	1	.007
Target * Native	.045	.112	.162	1	.688

The negative betas for Target Language (-.138) and Native Language (-.213) indicate that the Stress Light group and French participants (both coded 0) received worse scores than the Stress Heavy group and English participants. For all participants, Stress Heavy scored significantly higher than Stress Light (p < .05), and the English participants were significantly better than French (p < .05). There were no significant interactions.

The overall results suggest that the pattern of the Stress Heavy version was better learned than that of the Stress Light. However, since there are separate predictions for English and French learners, the following sections provide details of how each native language group performed.

4.2 English results

For the binomial logistic regression analysis the dependent variable was the probability of choosing the correctly stressed word and the independent variable was the target language, Stress Heavy or Stress Light. The independent variable was binary with Stress Light coded 0 and Stress Heavy, 1. Table 8 reports the results of a one-tailed test. Pilot work had led me to believe that it was reasonable to make a one-tailed prediction[2].

Table 8 English results on novel words

Variable	ß	SE	Wald Chi-Square	df	p
(Intercept)	0.479	0.057	71.429	1	.000
Target Language	-0.183	0.079	5.286	1	.011*

* one-tailed

The significant p-value of the Intercept ($p < .001$) indicates that participants in the Stress Light group's score of 57% correct was significantly more accurate than chance, 50%. The Stress Heavy group's score of correct responses was even better at 62% correct. While the raw difference in percentage scores is small, Target Language has a p-value of .011 showing that the unnatural, Stress Light, group performed significantly worse than the natural, Stress High group.

4.3 French results

As with the English, we were particularly interested in how accurately French speakers could identify the correct stress on novel words. The Stress Heavy group got 57% correct and the Stress Light group got 53% correct. The Stress Light group learned their pattern better than chance as indicated by the p-value of the Intercept for the Stress Light group ($p < .05$). The Stress Heavy group's score was even higher.

Table 9 reports the results of the analysis where Stress Light was coded 0 and Stress Heavy, 1. The Stress Heavy group's accuracy was higher than the Stress Light's and this difference was significant by a one-tailed test.

Table 9 French results on novel words

Variable	ß	SE	Wald Chi-Square	df	p
(Intercept)	0.265	0.055	22.802	1	.000
Target Language	-0.138	0.078	3.097	1	.039*

* one-tailed

2 Some statisticians do not agree that a one-tailed test is valid for this type of analysis. See http://www-01.ibm.com/support/docview.wss?uid=swg21482771 from SPSS for an explanation of the validity of dividing the p-value by 2 in the case of a directional hypothesis.

It seemed worthwhile to take a closer look to see what, if any aspect of the study was learned better by French speakers. Specifically, in the familiarization process participants were exposed to twice as many stressed initial syllables than medial and final syllables. Since stress is fixed on the final syllable in French, it is possible that French speakers might have exhibited a preference for words in the experiment that have stress on the final syllable, thus treating the target languages as they would their native language. However, since the dominant stress pattern was on initial stress, it is possible that learners could have performed better on initial stress in the novel words (Pater, 1997). I wanted to probe whether French speakers preferred their native final stress pattern, or whether they showed some preference for the initial stress pattern. Table 10 provides accuracy rates on the novel words based on the position of the stressed syllable.

Table 10 Novel word percent correct (SD) by syllable position

			French	English
Stress Position	Stress Heavy	Stress Light	Stress Heavy	Stress Light
Initial	48.64 (21.56)	48.64 (12.93)	62.95 (13.42)	54.32 (17.68)
Medial	61.59 (14.09)	57.50 (11.31)	66.36 (10.82)	56.14 (14.39)
Final	59.77 (8.93)	54.09 (14.93)	55.91 (12.88)	62.27 (13.78)

French participants in both the Stress Heavy and Stress Light groups were most accurate on words with medial stress and least accurate with initial stress. A binomial logistic regression with Stress Position as a three-level factor shows that there is a significant difference in stress position as seen in Table 11.

Table 11 Regression analysis by stressed position

Variable	β	SE	Wald Chi-Square	df	p
(Intercept)	.472	.098	23.211	1	.000
Target	-.170	.138	1.527	1	.217
Stress Position	-.527	.137	14.836	1	.000**

** indicates p < .001

A follow-up analysis shows that the significant difference is between initial and medial stress for both Stress Light (β = -.357, SE = .136, Wald Chi-Square = 6.921, p = .009); and Stress Heavy (β = -.527, SE = .137, Wald Chi-Square = 14.836, p <.001). There was no significant difference between medial and final stress.

Thus, increased exposure to initial stress in the familiarization words did not translate into greater accuracy with initial stress in the novel words. It is not surprising that French were accurate with final stress, as that is their native pattern. However, it is interesting to note that they were slightly more accurate on medial stress, indicating that some learning had occurred.

5 Discussion

The purpose of this study was to test whether participants would better learn a natural stress rule, where stressed syllables are heavy, over an unnatural one where stressed syllables are light. Stressed syllables in both the Stress Heavy and Stress Light languages had greater duration, pitch, intensity and perceptual energy than unstressed syllables. The results were that the natural Stress Heavy rule was better learned than the unnatural Stress Light rule. The Stress Heavy rule had a linguistic advantage, in that it was typologically and phonologically natural. Stress based on syllable weight occurs in many of the world's languages. But stress occurring on CV syllables while avoiding CVC syllables is not phonologically natural. Therefore the Stress Light group did not have a phonological advantage and thus did not learn that stress rule as well. The greater accuracy in choosing the correct syllable in the natural version suggests an emergent effect of the WSP. The WSP appears to exhibit some influence on acquisition of stress even if it is not exerting an influence in stress determination in the native language. That syllable weight influences stress assignment is solely a principle of language, not one of general cognition. Thus we can surmise that learners were able to tap into a purely linguistic principle to aid them in their acquisition.

It was interesting to note that in both the Stress Heavy and the Stress Light groups there was no significant difference between accuracy on the two sets of novel words. For the English-speaking participants in the Stress Light condition, the first set of novel words were more accurately identified than the second set of novel words, but this difference was not significant ($\beta = .132$, $SE = .088$, Wald's Chi-Square = 2.246, $p = .134$). French speakers were consistent in accuracy for both sets of novel words, regardless of the target language. These results suggest that learners might have extracted the underlying stress pattern, about as much as they could, after learning the first 16 familiarization words and did not need the input from the additional words. However, the first set of 18 novel words did not provide enough power to produce the full effect of the differences between the Stress Heavy and Stress Light versions.

For the unnatural Stress Light language, based on the input where they hear stress on light syllables, both language groups might propose an ANTI-WSP constraint to account for the stress pattern. Both French and English participants were less accurate with this stress rule. Since this is not a natural linguistic rule it is not surprising that the accuracy was reduced.

The experiment included English- and French-speaking participants to further probe whether the native stress pattern, variable vs. fixed, would have an effect on learning. English has a complex and variable stress pattern. While English speakers may be tacitly aware of stressed syllables being heavy, meaning that the WSP is active in English, they also hear and produce stress on light syllables in their native language due to the interaction of several constraints including the WSP, NONFINALITY, TROCHEE, ALIGN-LEFT and ALIGN-RIGHT among others (Pater 2000; Prince & Smolensky 1993/2004; Hammond 1999). Stress assignment in French is produced with fewer constraints than English since final syllable stress can largely be analyzed as a result of a high ranking of ALIGN-RIGHT over ALIGN-LEFT. It seems counterintuitive, but the variable stress pattern with its many constraints is more adaptable than the fixed stress pattern produced by just a few constraints. It remains an open question for further research into what facet or facets of variability provides an advantage to learning another variable stress system. One approach would be to see if this is a subset issue. While all languages contain the same universal set of constraints, it is possible that speakers of a language with a large set of *active* constraints that interact to produce a particular phonological pattern are better able to learn a language with a subset of the same active constraints, but the reverse does not hold. Clearly, more research needs to be done in this area.

English performance on the Stress Heavy language was not merely a transferring of the stress pattern of English to the Stress Heavy version because that rule is quite different from English stress rules. In fact, if English speakers learning the Stress Heavy rule were simply transferring their English knowledge to the new language, one would imagine that their accuracy scores would have been even higher[3].

French speakers in both target language groups performed worse than English speakers. Several factors may have influenced that outcome. Although the stimulus words were nonsense words in both English and French, the original syllables were recorded by an American speaker, so a non-French accent may have put the French at a slight disadvantage. In addition, for French speakers to learn both the Stress Heavy and Stress Light languages they have to switch, theoretically speaking, the ranking of ALIGN-RIGHT >> ALIGN-LEFT, which produces their native stress pattern, to ALIGN-LEFT >> ALIGN-RIGHT in order to identify the default pattern of initial stress in the target languages. Given their poor performance on initial stress, it appears that ALIGN-RIGHT has not been completely re-ranked and continues to affect French choice of

3 Compare English participants' scores of 70% correct on the natural version of a similar task where stress was attracted to low vowels over high vowels, a rule that is not a part of the English stress system (A. Carpenter, 2010).

correct stress. English also has ALIGN-RIGHT ranked over ALIGN-LEFT, but they were more accurate with stress on the initial syllable. A factor that could have aided the English speakers is that English has an undominated trochaic constraint, TROCHEE THAT demands that feet be left-headed. While the Stress Heavy and Stress Light languages do not have a trochaic bias, English speakers exposed to initial stress on half of the familiarization words as well as stress on heavy syllables, which could be analyzed as being bimoraic trochees (Hayes, 1995; McCarthy, 1979), might have analyzed the words as being trochaic. Misanalysis of trochees would be most apparent in the English Stress Heavy group, thus contributing to their better performance on the novel words. The English Stress Light group also heard initial stress on half the words, but only a few stressed heavy syllables. French, in contrast, does not have a trochaic bias so speakers have no native language impetus to move stress to the left. They have to depend solely on the linguistic input to trigger a realignment of stress.

Another factor that needs to be taken into account with the French is the effect of stress 'deafness' on their overall results. While the pretraining helped to train their ears to accurately identify stressed syllables, it is reasonable to assume that they still carried an additional cognitive load in processing stress (Dupoux et al., 1997). For example, Dupoux et al. (1997) found that in an AX identification task, French speakers could accurately identify stress. However, Dupoux et al. argued that the decreased ability of French speakers to retain the stress information was due to their not encoding the information abstractly (Dupoux et al., 1997, p. 418). The decision as to what linguistic elements require a mental representation differs from language to language, (for example, Japanese does not distinguish between /l/ and /r/, but English does). Since stress is not contrastive in French, speakers do not have to create a mental representation of stress. Therefore, French participants must exert more cognitive effort to analyze the incoming stimuli that varies in stress placement. This added cognitive effort most likely affected their accuracy in the task.

5.1 An additional English advantage?

It is possible that English speakers have an additional advantage with respect to learning the Stress Heavy language. That would be the case if English already has more stressed heavy than stressed light syllables in multisyllabic words in the language as a whole. If this were the case then English participants would be more likely to perform better on the Stress Heavy task because their accuracy would be an effect of a frequency pattern already existing in English. To see if this were so, a corpus study was done to evaluate the frequencies of stressed CVC(C) and CV syllables in American English speech[4]. The question we asked was, what is the ratio of heavy (CVC) to light (CV) stressed syllables in normal discourse in American speech?

The corpus used was the Switchboard Transcription Project (STP). The STP is comprised of several hundred recorded telephone conversations that have been phonetically transcribed and is considered to be "representative of spontaneous discourse" (www1.icsi.berkeley.edu/Speech/stp/). It includes function words as well as content words. A subset of the corpus, about 45 minutes in length, has been phonetically transcribed for stress on each syllable. Syllables with full stress are marked with 1, those with what is termed "intermediate accent" is marked with 0.5 and syllables that are unstressed are marked with 0 (Greenberg, Carvey, & Hitchcock, 2002). The two transcribers were instructed to label stressed syllables "on the basis of its perceptually based stress accent" and not according to knowledge of its stress pattern as expressed in a dictionary (Greenberg, Chang, & Hitchcock, 2001). The interrater reliability was 95% for stressed syllables. The values used for the current analysis were the average of the two transcribers' scores for each syllable. The stress-marked portion of the data included 14,219 syllable tokens, 4,935 syllable types and about 5,910 word tokens. To compute the number of stressed heavy (closed) and light (open) syllables we used a script that extracted the number of heavy and light syllables. We defined closed and open syllables as those with and without codas, respectively. Given that we were working with connected speech some of the syllables potentially spanned word boundaries. Table 11 summarizes the findings. Stress levels of .25 and .75 represent averages between levels 0 and 0.5 and 0.5 and 1.0.

4 Thanks to Srvanna Reddy for her assistance in running the corpus study.

Table 11 Number of Heavy and Light syllables from the STP corpus

Prosodic Stress Level	Heavy Syllables	Light Syllables	Ratio of heavy to light syllables
0	1903	3445	0.55
.25	47	88	0.53
.5	1085	1206	0.90
.75	36	35	1.03
1	1661	1669	1.00

Of the syllables rated with some form of stress, that is, those marked as levels 0.5 and above, 2782 are closed and 2910 are open, leading to an overall ratio of .95. This means that English speakers hear almost equal numbers of stressed CVC and stressed CV syllables in ordinary discourse. Figure 1 demonstrates that heard stress (level 0.5 and above) is equally divided between heavy and light syllables.

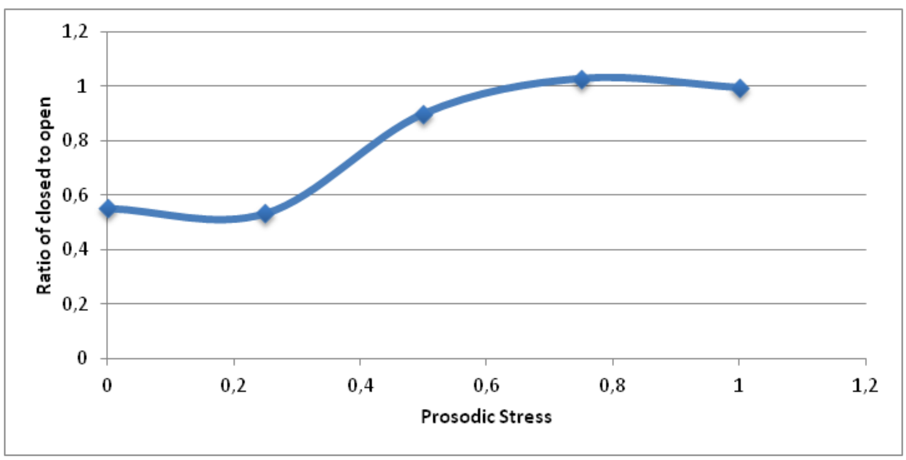

Figure 2. Ratio of closed syllables to open syllable by stress level

In summary, the STP corpus study reveals that when syllables are stressed in English the stress is about equally distributed between heavy and light syllables. This finding suggests that English speakers are not necessarily predisposed to prefer stress on heavy syllables based on the frequency of stressed heavy syllables. Thus, based on their knowledge of stress in English, learners of the Stress Heavy language do not necessarily have an advantage over learners of the Stress Light version.

5.2 General cognition vs. language-specific cognition

General cognition is necessary for learning. General cognitive factors include attention, memory (Baddeley 1999, Ellis 2001) and the ability to learn complex rules in nonlinguistic domains, such as visual perception (Lewicki, Czyzewska, & Hoffman, 1987; Maye, Werker, & Gerken, 2002; Stadler, 1989). The current experiments were designed to separate out the results of a general cognitive learning mechanism from a domain-specific language learning mechanism. The general cognitive task was the learning of the familiarization or training words through memorization aided by token frequency. The fact that French and English participants learned the training words for both languages equally well demonstrates the working of that general learning mechanism. It is interesting that French speakers learned the familiarization words well. Their performance indicates that the training task designed to help them to overcome stress 'deafness', at least for the time period of the experiment, was successful. Similar results were reported in Carpenter

(2015). While French and English participants performed well on the general cognitive learning task, the much lower scores on the novel word tests suggests an effect of a domain-specific language mechanism, which needs to extract the natural linguistic principle underlying the familiarization words. Based on the lower scores on the novel words than on the familiarization words, extracting the underlying stress pattern is a different and more difficult task than just learning the words. The results on the novel test words suggest that some mechanism other than one used for general learning aided the natural Stress Heavy group to better extract the underlying pattern being taught but that mechanism did not help the unnatural Stress Light group in the same way.

Could the same results be obtained by means of our general cognitive mechanism without the use of a domain-specific language mechanism? This is a reasonable question as we have seen that pattern generalization occurs in nonhuman species, including songbirds (Comins & Gentner, 2013), and rats (Comins & Gentner, 2013; de la Moro & Toro, 2014). For a review of nonhuman ability to extract and generalize patterns see (ten Cate & Okanoya, 2012). While there is no question that humans also generalize patterns, to learn the Stress Heavy rule better than the Stress Light one requires more than generalizing the underlying pattern. Otherwise, both groups would have learned the target languages equally well, as they did the familiarization words. General pattern recognition alone cannot account for the *difference* in learning between the Stress Heavy and Stress Light rules.

Some who propose that language-learning is solely a product of a general cognitive mechanism point to the fact that patterns such as sequentiality and frequency, which are common in language, are not domain-specific (Bybee, 2002). While frequency, for example, does play a role in language learning, notably in increasing the learner's familiarity with a particular sound or structure, frequency alone cannot account for learners' performance in these experiments. The frequency was controlled across both the natural, Stress Heavy, and unnatural, Stress Light versions, so all participants received the same number of exposures to the stress pattern in their respective target language.

5.3 Interaction between domain-general and domain-specific

Language learning, like other forms of learning, makes use of the same resources as other learning, such as memory and statistical frequency (Romberg & Saffran, 2010; Saffran, Aslin, & Newport, 1996). I propose however, that while there is a sharing of resources, there are language-specific areas of cognition that can be discerned by a task that focuses on that which is unique to language. For example, prominence is not unique to language, but prominence based on the abstract idea of syllable weight based on the rhyme is a uniquely linguistic principle. It seems likely that domain-general cognition shares its resources and mechanisms with the linguistic domain to facilitate learning a linguistic task. These mechanisms include memory, the ability to keep track of statistical regularities, and association of sound and pictures to aid learning. It is within this area of overlap that both the natural and unnatural stress rules can be learned in the familiarization task. However, internalizing the natural rule, to the extent that it can be, is facilitated within the domain-specific linguistic structure. Natural rules, like stress being attracted to heavy syllables, reside in the linguistic domain and input that 'matches' this feature is learned more easily. Input that does not 'match' is not learned as well, perhaps due to participants not having a good mental representation of its structure. That representation could include the WSP, or some similar version of the relationship between stress and syllable weight.

Clearly, more research needs to be done in the area of designing experiments that can tease apart the work done by a language-specific mechanism and that of general cognition in aiding language learning. Further, it would be interesting to gain a better understanding of the nature of the representations that distinguish linguistic input from those of general cognition.

In summary, the experiments reported in this paper support findings by others (Baer-Henney, Kügler, & van de Vijver, 2015; Becker et al., 2012; Moreton, 2008) that there is a learning bias for natural phonological structures over unnatural ones, and I argue that this bias is due to the effect of a mechanism specific to language.

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Appendix A

Instructions to participants

You are going to hear words in a language that you've never heard before. Then you'll be tested to see how well you can identify words that belong to that language. You will hear words with stress on different syllables. Stress can be described as the part of the word that sounds more prominent than the others. For example, we say baˈnana and not banaˈna. We can usually even decide which syllable should be more prominent in nonsense words, such as poeˈdektal and not ˈpoedektal.

In this language you will learn to do the same thing. After hearing several repetitions of words in the language, you will hear pairs of words that differ in their stress pattern. You will be asked to choose which word sounds like it belongs to the language you are hearing.

Please go as quickly as you can, but you have no time limit and you should be as accurate as possible.

Appendix B Familiarization words

Stress Heavy	Stress Light
ˈbiʃ.kuf.paʧ	ˈbiʃ.kuf.paʧ
ˈku.pi.ba	ˈku.pi.ba
ga.ˈpuf.tiʃ	kaf.ˈpa.bu
pi.bi.ˈtadʒ	padʒ.kif.ˈka
ˈkaf.pa,bu	ˈga.puf.tiʃ
ˈpadʒ.kif.ka	ˈpi.bi.tadʒ
gu.ˈbaʃ.tu	giʃ.ˈdu.taʧ
ku.di.ˈbuʃ	duʧ.paf.ˈka
ˈgiʃ.du.taʧ	ˈgu.baʃ.tu
ˈpaf.buʧ.tif	ˈpa.di.pu
pa.ˈkaf.didʒdʒ	dadʒ.ˈgu.ki
ta.pi.ˈkaf	dif.tuʃ.ˈga
ˈdadʒ.gu.ki	ˈpa.kaf.didʒ
ˈtuf.da.tuʧ	ˈti.dadʒ.pa
bi.ˈdadʒ.pa	tuf.ˈda.tuʧ
pu.di.ˈgaʃ	paʃ.guʃ.ˈtu
ˈpa.di.pu	ˈpaf.buʧ.tif
ˈdif.tuʃ.ga	ˈbi.ga.piʧ
ba.ˈkaʧ.pidʒ	baʃ.ˈdu.ta
bi.ga.ˈpiʧ	kaʃ.pif.ˈdu
ˈpuʧ.ku.guf	ˈki.tiʧ.da
ˈti.bu.da	ˈkidʒ.guʃ.tiʧ
ki.ˈtiʧ.da	puʧ.ˈku.guf
ti.ka.ˈbaf	baʃ.kaf.ˈdi
ˈguʧ.du.ta	ˈdu.kaf.tiʃ
ˈpaʃ.guʃ.ku	ˈti.pa.tudʒ
du.ˈkaf.tiʃ	kif.ˈpa.du
gu.pa.ˈtudʒ	pif.dadʒ.ˈbi

Appendix C Novel Words

	Stress Heavy Words	Stress Light Words
Novel Test 1-18	ˈbukadi	ˈbukadi
Initial Stress	ˈkaʃpika	ˈbafpudʒkiʃ
	ˈpuʃdiʃkaf	ˈdikutʃpif
	ˈbadʑkidudʒ	ˈbipatadʒ
	ˈkutʃgaku	ˈpugaʃtu
	ˈkadʒtifpaʃ	ˈgakidʒti
Medial Stress	gaˈkidʒda	kaʃˈpika
	diˈkutʃpif	kutʃˈgaki
	puˈgaʃtu	tatʃˈbapu
	buˈpuʃgaf	badʒˈdadudʒ
	guˈdidʒka	tufˈpagitʃ
	diˈgadʒpa	bafˈkitadʒ
Final Stress	pabiˈtadʒ	pufdiʃˈka
	bugaˈputʃ	kadʒtifˈba
	gukaˈtiʃ	bifkiʃˈda
	kipuˈduf	pafkuʃˈda
	tukiˈguʃ	pifgadʒˈdi
	dapaˈdadʒ	bifpatʃˈba
Novel Test 19-66	ˈbifkiʃda	ˈbupuʃgaf
Initial Stress	ˈditabu	ˈditabu
	ˈpafkuʃda	ˈbugaputʃ
	ˈpubaku	ˈpubaku
	ˈkiftagu	ˈgudidʒka
	ˈpifgadʒdu	ˈdigadʒpi
	ˈtufpagitʃ	ˈtupuduf
	ˈbafpudʒkiʃ	ˈkitadʒgu
	ˈtakipu	ˈtakipu
	ˈtatʃbapu	ˈkabidʒdutʃ
	ˈbifpatʃba	ˈtukatʃtif
	ˈbafkitadʒ	ˈpitʃguʃdif
	ˈdifkuʃtadʒ	ˈdifkuʃtadʒ
	ˈbugaba	ˈgukatiʃ
	ˈguʃkifpa	ˈdidʒkaftiʃ
	ˈputʃgagaf	ˈtikupif
Medial Stress	kaˈbidʒdutʃ	putʃˈgagaf
	diˈkatʃtif	gutʃˈkudif
	paˈdiftudʒ	bufˈgudiʃ
	gaˈputʃgiʃ	difˈkubadʒ

	Stress Heavy Words	Stress Light Words
	duˈpafbitʃ	gafˈpudutʃ
	biˈtudʒgaf	tutʃˈkibaʃ
	tuˈbidʒdu	paʃˈbikatʃ
	puˈpaʃtu	gitʃˈpadadʒ
	diˈtufbu	kufˈpita
	daˈpitʃga	patʃˈkabi
	paˈbuʃgu	badʒˈgutu
	kiˈpidʒta	pufˈkida
	piˈbatʃta	gufˈbiti
	piˈgaʃki	tadʒkipu
	duˈgiʃkaf	biʃˈgaka
	biˈkafguʃ	gaʃˈkubi
Final Stress	gapiˈduʃ	guʃkifˈpa
	biguˈpadʒ	paʃbidʒˈta
	pukiˈtatʃ	difkiʃˈpu
	pagaˈbitʃ	buʃgafˈpi
	pikuˈgaf	kitʃtatʃˈpi
	dubuˈgitʃ	tufbidʒˈpa
	duguˈbaf	batʃkidʒˈdu
	dabaˈkif	dadʒkifˈta
	gakaˈpif	gitʃpatʃˈtu
	gudiˈpudʒ	kaʤdudʒˈpi
	tupaˈdadʒ	pudʒkufˈda
	takiˈdif	tifgadʒˈdu
	kipuˈkiʃ	dutʃbiʃˈka
	bapiˈdadʒ	kaʃgufˈba
	kubaˈgaʃ	bidʒbuʃˈdi
	tikuˈpif	kudʒbiʃˈdu