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# Learning natural and unnatural phonological stress by 9- and 10-year-olds: A preliminary report

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**Abstract**

Research into adult learning of natural and unnatural pairs of artificial languages have demonstrated that it is easier to learn a phonological rule that is based on naturalness in language than a similar, but unnatural, version of the same rule (Wilson 2006, Carpenter 2010). Infants' learning of natural and unnatural phonology has produced mixed results (Gerken and Boltt, 2008; Seidl and Buckley, 2005). The present study focuses on older children's learning of a natural and unnatural version of a stress rule based on vowel height. The results show that 9- and 10-year-olds exhibit a bias towards the natural rule. I suggest that the bias develops from an interaction between general cognition and a language-specific one.

## 1. Introduction

A growing body of research using artificial language learning paradigms supports the finding that adults can demonstrate a learning bias for attested phonological patterns over unattested ones (see Moreton & Pater 2012 for a review). While not all research supports a learning bias (Chambers, Onishi, & Fisher, 2003; Peperkamp & Dupoux, 2007; Seidl & Buckley, 2005), many have found such a bias, attributed to either a substantive (some phonetic basis) or an analytic (a cognitive predisposition to acquire a particular type of pattern) reason. For example, Wilson (2006) found that learners exposed to a substantively-motivated velar palatalization pattern were more successful at generalizing that pattern to novel instances than those exposed to an unmotivated palatalization pattern. Moreton (2008) found an analytic learning bias for a phonotactic pattern where English speakers were better able to learn a height-height and voice-voice pattern in artificial CVCV words better than a height-voice one. In the area of phonological stress, Carpenter (2010) detailed an experiment where both English and French adults were able to learn more accurately a natural phonological rule where stress occurs on a low vowel than one where stress occurs on a high vowel. She attributes this result to an analytic bias towards naturalness. While there are various definitions for the terms 'natural' and 'unnatural', I use these terms to refer to a phonological pattern that is attested to occur in language ('natural') and one that is unattested to occur in language ('unnatural'). In addition to being attested, natural patterns are predictable theoretically as they conform to well-established phonological phenomena such as hierarchical scales (e.g. the sonority scale) or licit constraint rankings (Carpenter, 2010). Unnatural patterns go against hierarchical scales or call for illicit constraint rankings.

How do these naturalness biases develop? Infants display learning biases, learning simpler patterns over more complex ones (Chambers, Onishi, & Fisher, 2011; Cristia & Seidl, 2008) and phonetically similar over dissimilar sounds (White & Sundara, 2014). Infants' phonological learning suggests that a bias develops with age. For example, Gerken and Boltt (2008) found that nine-month-old infants were able to generalize a pattern assigning stress to heavy (CVC) syllables, a common pattern in the world's languages, but not one assigning stress based on syllable onset, a rare pattern in language. In a similar experiment, however, 7.5 month-olds could also generalize the unnatural pattern. They concluded that the bias develops over time. On the other hand, not all biases are evidenced in infants as seen in Seidl and Buckleyˈs

(2005) experiment with 9-month olds where they learned phonologically unnatural and natural patterns equally well. Thus, while we have some evidence that infants and adults are better able to learn a phonological rule that follows a natural or attested pattern, much is still unclear about phonological biases in older children, as there has been little work done in that area.

This paper is a preliminary report on an artificial language-learning study conducted with 9- and 10-year-old children that investigates whether they demonstrate a learning bias for a natural stress pattern over an unnatural one. The experiment described in this paper is underlyingly one that tests second language learning and compares acquisition of two stress rules by children and adults. Nine- and ten-year-olds were chosen as the comparison group for two primary reasons. First, they are pre-adolescent and arguably within the critical period where children may have an advantage in second language acquisition. Although there is much controversy about whether a critical or sensitive period for second language acquisition exists or at what age such a period may end (see Singleton 2005 for a summary) many researchers agree that younger children appear to have at least a phonological advantage in second language learning (Diller, 1981; Johnson & Newport, 1989; Scovel, 1988; Seliger, 1978). Since one of the goals of this study was to compare child learning to adult it was important to use the same experimental methodology. Therefore, a second reason to focus on children in the 9- to 10-year age range was to take advantage of their developing ability to learn in a similar manner as adults. Learning research shows that the method of teaching then testing enhances learning in the situations where participants are tested on novel material (Rohrer, Taylor, & Sholar, 2010). This is referred to as the 'transfer effect'. Pilot testing with this methodology showed that children younger than nine did not learn nonsense words effectively and corroborates previous findings in the literature where the transfer effect “disappeared for students younger than 8 years of age” (Rohrer et al., 2010). Although infants have demonstrated a bias for a natural phonological pattern over an unnatural one (Gerken & Bollt, 2008) it is not a foregone conclusion that language development is a straight upward path in the same direction. For example, early learning of morphology in toddlers often demonstrates a U-shaped development wherein children may accurately produce an irregular past tense, such as 'went' but later they incorrectly produce 'goed' (Ervin & Miller, 1963; Kuczaj II, 1977). Thus, probing for evidence of a naturalness bias in older children is useful for mapping the developmental path between infants and adults.

The natural – unnatural pair of stress patterns used is an adaptation of those in Carpenter (2010) where vowel height determines stress placement. In languages where vowel height attracts stress it is usually the case that stress prefers low vowels over high vowels (de Lacy, 2002; Hayes, 1995). The generalization found in these languages is that stress is attracted to low vowels and thus, this is a natural pattern, that is, one that is attested to occur in real languages. The converse pattern, stress being attracted to high vowels when low vowels occur in the language, is not attested to occur in language, all else being equal (de Lacy, 2002; Hayes, 1995). The group taught that pattern in the experiment is therefore learning what we call an 'unnatural' language.

Previous research has shown that both English-speaking and French-speaking adults are better able to learn a natural phonological rule where stress occurs on a low vowel than one where stress occurs on a high vowel (Carpenter, 2010). The current study exposes two groups of children to nonsense words that have an underlying stress pattern, tests them on the specific words taught, and then tests them on previously unheard novel words that have the same stress pattern. One set of children, the Stress Low Vowel group, were taught a natural stress pattern in which stress is attracted to low vowels [a] and [æ], and the other group, Stress High Vowel, learned an unnatural pattern where stress is attracted to high vowels [i] and [u]. The prediction was that the Stress Low group would be more accurate at generalizing to novel words than the Stress High group.

This study also seeks to compare child results to adult results from Carpenter (2010) to ascertain whether there are age-related differences that could reflect the development of a naturalness bias. In order to compare children's results with that of adults it is necessary to create a similar learning situation so that a fair comparison can be made. To that end, the experimental methodology and materials modified that of Carpenter (2010) to accommodate children's shorter attention span. The modifications included adding animation and graphics to add more visual interest to keep children's attention and explaining the experiment as a 'game' where participants would accumulate 'points' towards winning a prize at the end.

## 2. Method

*Participants*

Participants were 9- and 10-year-old children who were native speakers of American English, with no known hearing problems as reported by their parents. The children were recruited through the principals and teachers of several public schools in eastern Massachusetts and one private school in suburban Philadelphia. Teachers reported that all children were within the normal range in their reading and listening skills. All the appropriate human subjects guidelines were followed and consent forms were signed by each child and his or her parent.

Of the 56 children who participated in the study, 26 were omitted for not meeting criteria, 11 from the Natural group and 15 from the Unnatural, leaving a total of 30 participants, 14 in the Natural group and 16 in the Unnatural. Despite modifications to the methodology, individual children often failed to achieve criteria, perhaps due to differences in working memory capacity (S. Gathercole, Pickering, Ambridge, & Wearing, 2004). All participants (13 male, 17 female) were randomly assigned to one of two language conditions, the natural Stress Low or the unnatural Stress High.

Participants were taught and tested on one of two stress rules. The Stress Low group was presented with 3- and 4-syllable words where stress occurred on the first syllable with a low vowel and if all syllables were low or if all syllables were high, then stress was on the initial syllable. For the Stress High group, stress occurred on the first syllable with a high vowel, and if the vowel height of all the syllables was the same, then stress was on the initial syllable.

*Stimuli*

*Creating the syllables*. Three- and four-syllable nonsense words were created from syllables recorded by a trained male phonetician, who is a speaker of American English. The syllables, all CV, were built from an onset set of voiced and voiceless consonants, [b, d, g, p, t, k] and the fricatives [s] and [z]. The vowel inventory was comprised of the high vowels, [i] as in *beet* and [u] as in *boot*, and the low vowels [æ] as in *bat* and [a] as in *pot*. In total there were 32 different syllables: eight consonants combined with four vowels.

To create the stimuli, the target syllables were recorded within the carrier phrase, "Mike _____ Karinna Jones," by the trained male phonetician. Before concatenating, syllables beginning with a stop were cut just before the burst and approximately 5 msec. of silence was added before the burst of each voiced stop syllable and 10 msec. before the burst of each voiceless stop syllable. No silence was added to the fricative syllables. Syllables beginning with a fricative were cut at the beginning of the frication. In addition, all syllables were scaled to fit a spectral envelope with a 5 ms. leading edge, and a 5 ms. trailing edge.

The low vowels [a] and [æ] are inherently longer than the high vowels [i] and [u]. To neutralize this durational advantage for the Stress Low rule, vowel lengths were equalized (within 5 ms.) for all syllables in a way that retained the natural variation between syllables with different onsets. In addition, intensities were also equalized to negate the higher intensity found in the high vowels. These adjustments were made to remove any inherent phonetic bias between the vowel types and to equalize, as much as possible, the phonetic cues given to learners of the natural and unnatural Stress High languages.

The correlates of stress on a syllable are duration, pitch and amplitude. To maximize the perceptual difference between stressed and unstressed syllables for both the Stress Low and Stress High conditions, further adjustments were made in the duration and pitch of the syllables in the following ways for stressed syllables:

a) Duration of the vowel was increased by 20%

b) Pitch was increased by 20% and a pitch contour was added based on the syllable position. Syllables in the initial stress position of the word have a falling contour, syllables for the medial stress position received a rising then falling contour and syllables for the final stress position received a rising contour.

c) For unstressed syllables, amplitude was reduced by 6 dB.

With these changes, pilot testing showed that adult subjects could reliably (nearly 100% of the time) pick out the stressed syllable in three- and four-syllable words.

*Creating the words*. Three- and four-syllable words were created by combining the stressed and unstressed CV syllables described above. Please refer to Appendix 1 for a list of all the words used in the experiment. For the natural Stress Low language the possible types of words with three-syllables are: (where H = high vowel and L = low vowel) HHH, HHL, HLL, HLH, LLL, LLH, LHL, and LHH. Of these eight types initial stress occurs on five patterns of words: LHH, LLH, LHL, LLL and HHH; medial stress falls on HLL and HLH words and HHL alone attracts final stress. The unnatural Stress High language has the opposite stress pattern in that initial stress occurs either on words that have a high vowel syllable in initial position or words that have all high vowels or all low vowels. Medial stress is attracted to words where the initial syllable is a low vowel and the medial syllable is high and final stress occurs on LLH words. There were 16 possible types of words with four syllables and a similar pattern of combining low and high vowel syllables was made to produce words with initial, medial and final stress. For example, in the Stress Low language, a four-syllable word with stress correctly placed on the second syllable could be made up of one of the following types, HLLL, HLLH, HLHH, and HLHL.

*Procedure*

The experiment was described to the children as a learning game with levels in which there was a learning part and a 'challenge' part. They were told that they were to learn words in a new language in the learning part and then would be tested on those words in the challenge sections. After completing one level, they moved on to the next level with new words. They were told that throughout the game they would receive points for getting correct answers and win a prize at the end. At the end of the experiment all children saw the message that they had gained enough points to win a prize, regardless of their performance on the experiment.

Before beginning the experiment children were given a brief explanation of a stressed syllable along with verbal examples. For example, the researcher said an English word with correct stress (e.g. *ˈtelegraph, matheˈmatics*) and asked the child to identify the stressed syllable. They then donned headphones and began the pretraining exercise and then proceeded to the main experiment.

The pretraining words were 3- and 4-syllable CV words created in the same manner as the rest of the stimuli. Pretraining ensured that the children could correctly identify pairs of words with the same stressed syllable. The pretraining consisted of an AXB task in which participants were presented with nonsense words where A and B are stressed on a different syllable and X matches either A or B as to stressed syllable. The task was to indicate whether either the first two words or the second two words had stress on the same syllable. The triplet of words were segmentally the same but differed as to stressed syllable, such as ˈ*biguti* –ˈ*biguti* – *biguˈti*. After hearing 5 practice trials participants were scored on the following 24 trials. After the AXB pretraining task children proceeded onto the main experiment ,but data was analyzed only for those who reached criterion of at least 67% correct on the pretraining.

The main study consisted of a series of familiarization/training and testing blocks where participants were exposed to a set of familiarization words and then tested on those words. Each familiarization word was accompanied by a photographic image as a learning aid and to keep the child's interest. The images were items such as a leaf, a bicycle, a mask, etc., designed to provide a meaning for each word and also to establish that the nonce words being heard were nouns. The artificial word used bore no similarity to the English word for the object pictures. The training consisted of two blocks of four 3-syllable words and two blocks of five 4-syllable words, for a total of 18 familiarization words. The learner was first presented with a block of four 3-syllable words, tested on that block, then presented with a block of five 4-syllable words and tested on just that block. The training required the participant to listen to each word along with its accompanying image. Each word/picture combination lasted one second and was randomly repeated four times in a block. The randomization meant that some word/picture combinations were repeated two or more times in a row. After each training block learners were tested on just the words in that block.

All testing was in the form of a two-alternative forced choice task where participants were presented with a correct and an incorrect version of each word. While hearing the two choices, the child continued to view the accompanying picture on the screen. For example, participants heard ˈ*badaka* – *baˈdaka* and had to choose which version was correct. To make a choice, they pressed "1" if they believed the first word presented was correct and "2" if they believed the second word was correct. These numbers were written on colored tags placed over the "z" and "/" keys, which are on opposite sides of the keyboard to decrease the chance that learners would accidentally press the wrong key. After choosing, the participants received feedback, which stated the correct answer. If the answer was correct the message, "You've earned 10 points!" flashed on the screen for one second immediately followed by a celebratory animation such as fireworks or a dancing figure for two seconds. Immediately following the animation they saw the phrase, "The correct answer is:" and heard the correct version of the word. If the response was incorrect they simply saw the phrase, "The correct answer is:" and heard the correct version of the word. Following the first two training/testing blocks, children listened to a review of those first nine words, repeated twice and then were tested on those

words. The same process was repeated for a new set of four three-syllable words and five four-syllable words and once again they were tested on the 9 words. After a review of all 18 words they were given a test of all 18 familiarization words. The children were then tested on 36 novel words that they had not heard before. Novel test words had no accompanying picture. All words presented for the training and testing portion were balanced between the two conditions as to number of syllables (3 and 4), location of stress and types of words (HHLL, HHH, etc.).
*Novel words*. Novel words were used to test how well the children had acquired the target stress pattern, either Stress Low or Stress High. The novel words were similar to the training words in syllable composition. The novel word test, however, was more difficult than the familiarization words because the children had never been exposed to those words before. During the novel word test, participants heard each word presented with the on-screen written instruction: "Press 1 if the first word is correct or press 2 if the second word is correct." Table 1 outlines the structure of the experiment.

Table 1 Experiment design

| | | |
|---|---|---|
| a. | Pre-training | Participants perform AXB test and reach criterion (67% correct) |
| b. | Familiarization Block 1 | Participants hear four 3-syllable familiarization words, randomly repeated 4 times, with an accompanying photographic image. |
| c. | Testing Block 1 | Participants tested on the four words just heard with feedback. |
| d. | Familiarization Block 2 | Participants hear five 4-syllable familiarization words, randomly repeated 4 times, with an accompanying image. |
| e. | Testing Block 2 | Participants tested on the five words from familiarization Block 2, with feedback |
| f. | Review | Participants listened to the first nine words repeated twice. |
| g. | Testing Block 3 | Participants tested on the first nine words, with feedback. |
| h. | Familiarization /Testing Blocks 4 and 5 | Same as Blocks 1 and 2 above. Each familiarization block presents new words. |
| i. | Review | Participants listen to the $2^{nd}$ nine words learned in blocks 3 and 4, each repeated twice. |
| j. | Testing Block 6 | Participants tested on the $2^{nd}$ nine words, with feedback. |
| k. | Review | Participants listen to all 18 words, repeated twice. |
| l. | Testing Block 7 | Participants tested on all 18 words, with feedback. Criterion is 60% correct. |
| m. | Novel Test | Participants presented with 36 novel test words consistent with the pattern they have been learning. They do not get any feedback. |

## 3. Results

Participants had to pass the criterion of getting at least 60% correct on the familiarization words in order to be included in the analysis. There were 14 participants in the natural Stress Low condition and 16 in the unnatural Stress High. Table 2 details the proportion correct of the training and novel words by language, natural and unnatural.

Table 2 Proportion correct (SD) of familiarization words and novel words

| **Language** | **Natural** | **Unnatural** |
|---|---|---|
| Familiarization words | .70 (.09) | .71 (.07) |
| Novel words | .53 (.07) | .46 (.08) |

Children who passed criterion in the Stress Low condition averaged 70% correct and those in the Stress High condition averaged 71% correct. There was no significant difference between these scores so both groups learned their respective familiarization words equally well. Scores on the novel words indicated how well the children had internalized the stress pattern to which they were exposed. Those learning the Stress Low rule scored 53% correct and the Stress High group averaged 46% correct. Figure 1 illustrates the spread of the scores on the novel words.

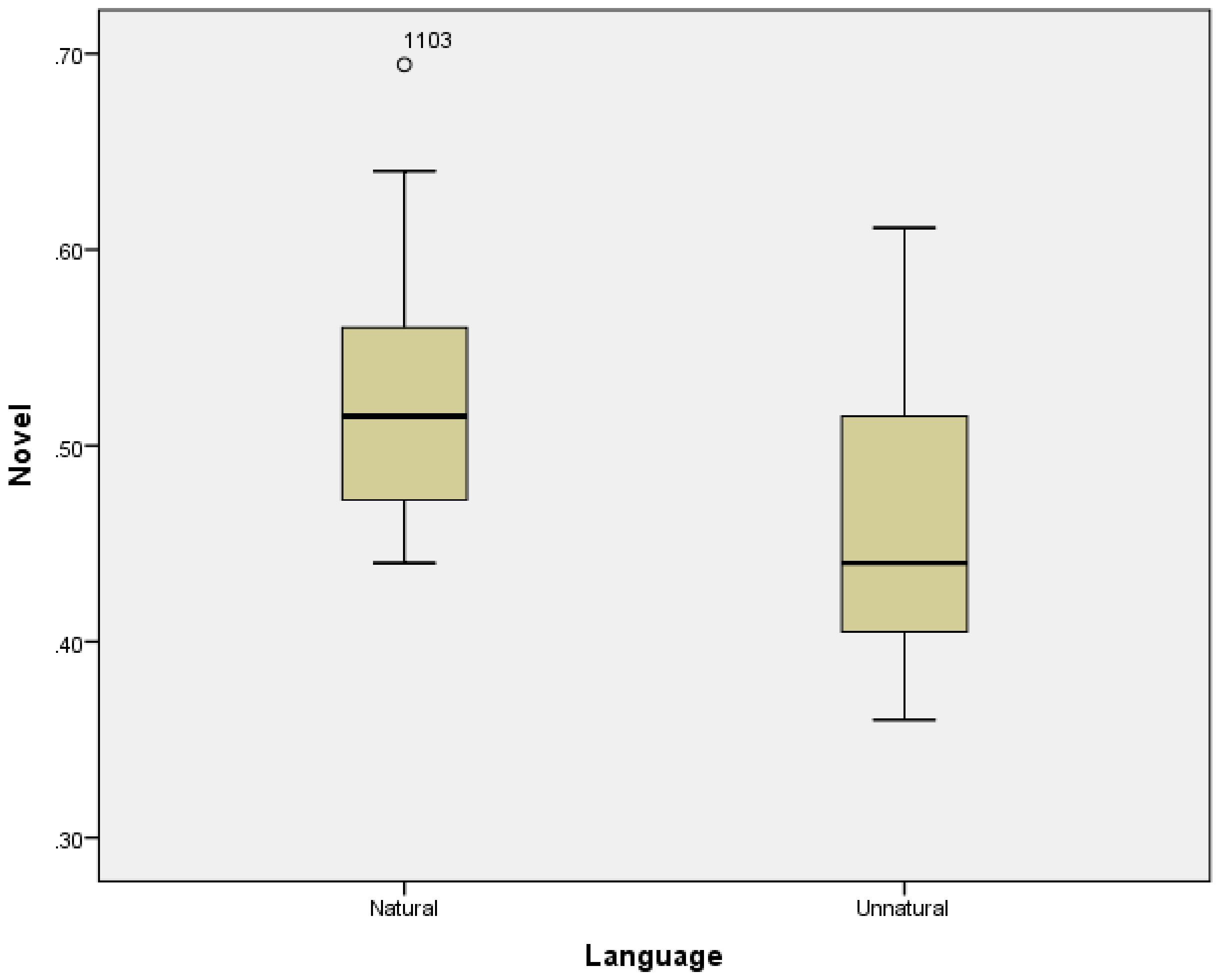


Figure 1: Proportion correct of the novel words in the Natural and Unnatural groups

Analysis was done using the R software program (R Core Team 2013) and the models were fitted using the lme4 package. The dependent variable was correct responses on each trial where 1 was correct and 0 was incorrect; all predictors were sum coded. A binomial logistic regression analysis with target language as the fixed effect showed there was a significant difference between the two scores, ß = .14, z = 2.21, p = .03.

Because the children's performance on the novel words did not differ from chance, post-hoc binomial tests were performed to see whether each group's accuracy differed from chance given the choices they had to make in the task. For example, the Stress High vowel group learned a rule where the first high vowel was stressed. In the novel word testing they were presented with pairs of words, one correct and one incorrect, but the incorrect choice could be a stressed low vowel, such as *ˈpugædu ~ puˈgædu* (correct ~ incorrect); or it could be a stressed high vowel but on the wrong syllable, such as *ˈsupiba ~ suˈpiba* (correct ~ incorrect). If participants made an incorrect choice by choosing a low vowel more often it could indicate that they preferred stressed low vowels, even though they were trained on stressed high vowels. Looking at just the pairs where the incorrect choice was the opposite of the stress rule on which they were trained, Table 3 lists the proportion of correct answers and the significance value with respect to a chance level of .50.

Table 3 Proportion correct for children based on vowel choice

| **Target Language** | **Correct choice** | **Incorrect Choice** | **% of total** | **Mean Correct** | **p-value** |
|---|---|---|---|---|---|
| Stress Low (Natural) | Low Vowel | High Vowel | 78% | .54 | .106 |
| | Low Vowel | Low Vowel | 22% | .49 | .925 |
| Stress High (Unnatural) | High Vowel | Low Vowel | 78% | .44 | .018* |
| | High Vowel | High Vowel | 22% | .52 | .791 |

* significant at p < .025

The results show that children who learned the Stress High rule when presented with a choice of a stressed high vowel or a stressed low vowel got only 44% correct, meaning that they chose the word with the low vowel 56% of the time. The 44% correct rate was significantly less than chance. This result suggests a preference for stress on low vowels, even after being trained on words with stress on high vowels.

Child results were compared with adult results from Carpenter (2010), which used the same stimuli[1]. Both children and adults were trained in the same manner as described previously. Table 4 shows the proportion correct and standard deviation of familiarization and novel words by both children and adults.

[1] Adults were first taught 18 familiarization words then tested with 18 novel words. Children in the current experiment were taught the same 18 familiarization words and tested on the same 18 novel words. Children's results are compared to adult results in the first novel word test reported in Carpenter (2010).

Table 4 Proportions correct (SD) by Children and Adults on Familiarization and Novel Words

| | **Familiarization Words** | | **Novel Words** | |
|---|---|---|---|---|
| | **Natural** | **Unnatural** | **Natural** | **Unnatural** |
| Children | .70 (.09) | .71 (.07) | .53 (.07) | .46 (.08) |
| Adults | .87 (.10) | .82 (.14) | .71 (.14) | .61 (.14) |

A logistic mixed effect regression model was used to analyze the data. Fixed effects were Age (adult, child) and Target Language (Natural, Unnatural) and their interaction. Random effects included by-subject intercepts and by-item intercepts and slopes for Age. Children performed significantly worse than adults in both the training and novel words. For the familiarization words there was a main effect of age with adults being more accurate than children ($z = 5.24$, $p < .001$). There was no main effect of target language nor a significant interaction (zs < 1.1, ps > .27). For the novel words accuracy was higher for natural items than unnatural items (ß = .18, $z = 2.58$, $p < .01$). Adults had higher accuracy than children (ß = .36, $z = 5.05$, $p < .001$). There was no significant interaction of the two variables (ß = .03, $z = .49$, $p = .61$).

## 4. Discussion

In this study 9- and 10-year-old children were taught one of two artificial stress rules: stress the first syllable with a low vowel (Stress Low) or stress the first syllable with a high vowel (Stress High) and if all the vowels were the same height, then stress the initial syllable. The Stress Low rule reflects a pattern found in natural languages, while the Stress High rule is not. After being exposed to the stress rule, children were tested on novel words to see how well they had generalized the target stress pattern. The goal of the study was to compare the accuracy on novel words by children learning the Stress Low (natural) rule versus those learning the Stress High (unnatural) rule. The results show that while children did not perform very well overall, those in the unnatural Stress High condition performed significantly worse than those in the natural Stress Low group. This result is similar to that reported by adults doing the same task.

Since all the vowels, both high and low, were equalized as to length and intensity, neither adults nor children could have been aided by an actual durational or intensity difference between the vowels. This suggests that the learners were making use of a phonological principle, rather than just the phonetic stress cues of pitch, duration and intensity. While Naranjo & Zaleska (2015) suggest that native language could influence a naturalness bias, this would not seem to be the case here. Although English has a complex set of rules that determine stress (Prince and Smolensky 1993/2004; Hayes 1995), vowel height is not one of those determiners (although cf. Rice (1996)). Nevertheless, to investigate whether English knowledge might have affected the results, it would be worthwhile to test children (and adults) on the natural and unnatural stress patterns without giving them any training whatsoever[2]. This is an area for further research.

Greenwood (2015) in a similar artificial language learning task that tested adults on their learning of a simple, complex or unnatural pattern, found that the simple pattern was learned

[2] I thank an anonymous reviewer for this suggestion.

easier than the unnatural and complex ones. Interestingly, a follow-up study showed that participants listening to the stimuli from all three patterns were less accurate in reporting stress placement in the unnatural words. She suggests that the lower score of the unnatural group was due to a perception problem since unnatural stress seems to be more difficult to perceive. While this is an interesting suggestion a difference in perception does not seem to be the case in this study since the children in both groups performed equally well on their respective familiarization words. The natural group got 70% correct and the unnatural 71%. These similar scores indicate that both groups perceived the stressed syllables at about the same level.

It is to be noted, however, that children learned the training words at a significantly lower accuracy rate than adults and were much poorer at generalizing to the novel words than adults. Adult superiority over children in this type of learning task is supported by these results (Service, Yli-Kitala, Maury, & Kim, 2014; Snow & Hoefnagle-Hoehle, 1978). The familiarization task required that children memorize the familiarization words aided by their accompanying image and 26 of 56 failed to get at least 60% of these words correct. I surmise that this is due to individual differences in working memory capacity (S. E. Gathercole, Willis, Baddeley, & Emslie, 1994; Yuill, Oakhill, & Parkin, 1989). Children's working memory continues to develop during the 9- and 10-year range and is usually not as advanced as that of adults (S. Gathercole et al., 2004) so it is not surprising that they did not learn the familiarization words as well as adults did. Nevertheless, children were sensitive to the difference between the natural and unnatural stress rule as particularly seen in the Stress High group. That group showed a leaning towards low vowels, as evidenced by their low accuracy score when having to choose between a correct high vowel and an incorrect low vowel. This preference for low vowels, even after being trained on stressed high vowels, suggests at least a weak effect of a naturalness bias.

It is difficult to determine exactly the nature of the mechanism that facilitates a learning bias for natural patterns. On the one hand, one could argue that a mechanism specific to language supports a learning bias specific to patterns found in language (Chomsky, 1965; Pinker, 1994). On the other hand, some argue that a general cognitive mechanism is sufficient to learn language-based biases (Christiansen & Chater, 2008; Wonnacott, 2011). While adults have better memories and more highly developed cognitive abilities than children and are better able to learn in general (DeKeyser, 2012; Droit-Volet, Wearden, & Delgado-Yonger, 2007; S. E. Gathercole, 1999), research into child and adult second-language acquisition has shown that children have the long-term advantage over adults at acquiring the phonology of a second language (Aoyama, Emil, Guion, Akahane-Yamada, & Yamada, 2004; DeKeyser, 2012; Guion, Flege, H., & Yeni-Komshian, 2000; Munro, E., & Mackay, 1996). Thus, if children performed better than adults on this artificial language learning task, one could have surmised that the child advantage was due to a language-specific learning mechanism rather than to general cognition. However, if adults performed better than children then the idea of a domain-general cognitive ability would gain more traction. What we have here are mixed results. Adults scored higher than children for both the training and novel words. This result indicates a strong role for general cognition. However, children, despite their poorer scores, still performed better on the natural rule than on the unnatural one.

These mixed results suggest an interaction between general cognition and a domain-specific one. The adult-child overall differences in scores reflect a difference in cognitive development between adults and children. Research has shown that while children outperform adults in ultimate attainment of a second language, adults are better than children at learning a second language in other contexts, especially when they are being explicitly taught (DeKeyser, 2012; Krashen, Long, & Scarcella, 1979). Thus, given the limited time of the training in these experiments along with adults' more developed cognition, especially memory, it is not surprising that adults were better at learning the training words and were more accurate than children at correctly identifying the novel words in their respective target languages.

These preliminary results suggest that children do have some ability to tap into a naturalness bias in learning phonological stress. However, the generally lower scores also indicate a strong role for domain-general cognitive capacities, particularly working memory. To fully test these results would require having a larger participant pool to provide the experiment with more power. A further enhancement to the present experiment would be to have more child participants with similar working memory capacity. In this way we could further explore the interaction between domain-general cognition and the domain-specific language mechanisms that produce and sustain a naturalness bias in language.

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Appendix

A) Pretraining words for both Natural and Unnatural group

| | |
|---|---|
| babæbibu | padaziba |
| badagiku | pigægikæ |
| bæsizuku | pæsizæta |
| bukuzæti | sæbikæ |
| dakabæzu | satatadu |
| dubaki | sibægatu |
| gadipu | tædipikæ |
| gæbisuka | tazutu |
| gitibæ | zæbasi |
| gupægæ | zibabæzi |
| kaziti | zudibu |
| kidædi | zukægibi |

B) Familiarization words 'æ

| | Natural language | Unnatural language |
|---|---|---|
| Familiarization words 1 | 'badaka | 'buduku |
| | 'gikusi | 'gækasæ |
| | zu'pæta | za'pitu |
| | tigu'sa | tæga'su |
| Familiarization words 2 | 'zakipizu | 'zukæpæza |
| | 'kæsuzaga | 'kisazugu |
| | tu'gabupa | ta'gubapu |
| | ziki'pasæ | zækæ'pusi |
| | digitu'za | dægæta'zu |
| Familiarization words 3 | 'pætibu | 'pitæba |
| | 'tægika | 'tigæki |
| | ki'bapi | kæ'bupæ |
| | budu'gæ | bada'gi |
| Familiarization words 4 | 'datibisæ | 'dutæbæsi |
| | 'bakabæzu | 'bukubiza |
| | si'tækaza | sæ'tikuzu |
| | kubu'sæka | kaba'siku |
| | situguz'æ | sætaga'zi |

Novel words

| Natural language | Unnatural language |
|---|---|
| ˈkækibi | ˈkikæbæ |

| | |
|---|---|
| ˈsæpatu | ˈsiputæ |
| ˈsapæbu | ˈsupiba |
| ˈdædugu | ˈdidaga |
| ˈpagida | ˈpugædu |
| ˈgætusæ | ˈgitasi |
| buˈzata | bæˈzutu |
| tiˈgæti | tæˈgitæ |
| diˈpaga | dæˈpugu |
| biˈgadu | bæˈguda |
| suˈtasi | saˈtusæ |
| ziˈkæda | zæˈkidu |
| kukiˈpæ | kakæˈpi |
| zupiˈzæ | zapæˈzi |
| tuguˈza | tagaˈzu |
| pigiˈsa | pægæˈsu |
| tukiˈka | takæˈku |
| duzuˈdæ | dazaˈdi |
| ˈzæbadusæ | ˈzibudasi |
| ˈgætubæbæ | ˈgitabibi |
| ˈzupitisi | ˈzapætæsæ |
| ˈtapagiki | ˈtupugækæ |
| ˈpæsadazæ | ˈpisuduzi |
| ˈkapatapa | ˈkuputupu |
| ziˈbatikæ | zæˈbutæki |
| duˈsæbutu | daˈsibata |
| piˈpæbatu | pæˈpibuta |
| suˈpæsaba | saˈpisubu |
| pikuˈbætu | pækaˈbita |
| supuˈdæka | sapaˈdiku |
| diziˈbæpa | dæzæˈbipu |
| bipuˈbapu | bæpaˈbupa |
| dudizuˈpa | dadæzaˈpu |
| sigibiˈtæ | sægæbæˈti |
| gutukiˈda | gatakæˈdu |
| zibuguˈka | zæbagaˈku |