Experimental Investigation of the Subregular Hypothesis

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1. Introduction

Language patterns have many levels that pose different learning challenges to the learner according to their inherent difficulty. The Chomsky Hierarchy (Chomsky, 1956), a categorization of formal grammars, is one representation of such inherent complexity. This paper examines whether the learnability of specific phonotactic patterns is restricted to particular subregular regions of the complexity hierarchy. The specific theory about phonotactic patterns and their learnability that I test is the Subregular Hypothesis (Heinz, 2010) which claims that the learnability of phonotactic patterns depends on specific computational properties. This research falls into the general aim of examining whether behavioral learning of artificial but natural-language-possible phonotactic rule types will lead to observable real-time phonotactic parsing predictions. The main idea of this approach is illustrated with experiments testing the learnability of attested vs. unattested computationally different long-distance patterns.

I take as a point of departure the demonstration by Lai (2015), which shows that the phonological learner is restricted by Subregular computational constraints. This finding will be re-assessed experimentally by a behavioral experiment using the same training paradigm but a slightly different testing paradigm. Section 1.2 highlights some of the previous work and section 1.3 makes clearer our own motivation and contribution.

I am particularly interested in understanding how well long-distance subregular patterns, e.g., First-Last Assimilation rule, are learned. As will be explained in the following sections, these simple regular patterns encode certain types of long-distance dependencies which are unattested in human languages. I compare the performance of human subjects on these patterns with their performance on learning attested long-distance patterns, e.g., Sibilant Harmony rule, another instance of a subregular pattern. I hereby introduce the oddball paradigm to an artificial grammar learning experiment as a design parameter and the sensitivity index (d') as a measurement of learnability. The experimental details are explained in §2.

The results, presented in §3, show that the earlier findings that an attested and computationally learnable pattern is inside the hypothesis space of humans' phonological pattern detectors are replicated. Additionally, I demonstrate that sensitivity levels for the unattested and computationally difficult patterns appear to falsify the strong *Subregular Hypothesis* that they are not learnable. Implications of these results are discussed in §4. The paper concludes with §5 by supporting a weaker version of the *Subregular Hypothesis* that phonotactic patterns that reside inside of specific subregular regions are easily learned compared to those that reside outside of them.

1.1. Background: The Subregular Hypothesis

The Chomsky Hierarchy divides all logically possible patterns into nested regions of complexity (Chomsky, 1956) (see Figure 1 below). Each of these regions has multiple mathematical definitions that enable any machine or algorithm to generate the strings comprising the pattern (Harrison, 1978; Hopcroft et al., 2006).

Phonological patterns belong to the regular region in this hierarchy (Johnson, 1972; Kaplan & Kay, 1994). Heinz (2010) further shows that phonotactic patterns in natural languages inhabit proper subsets

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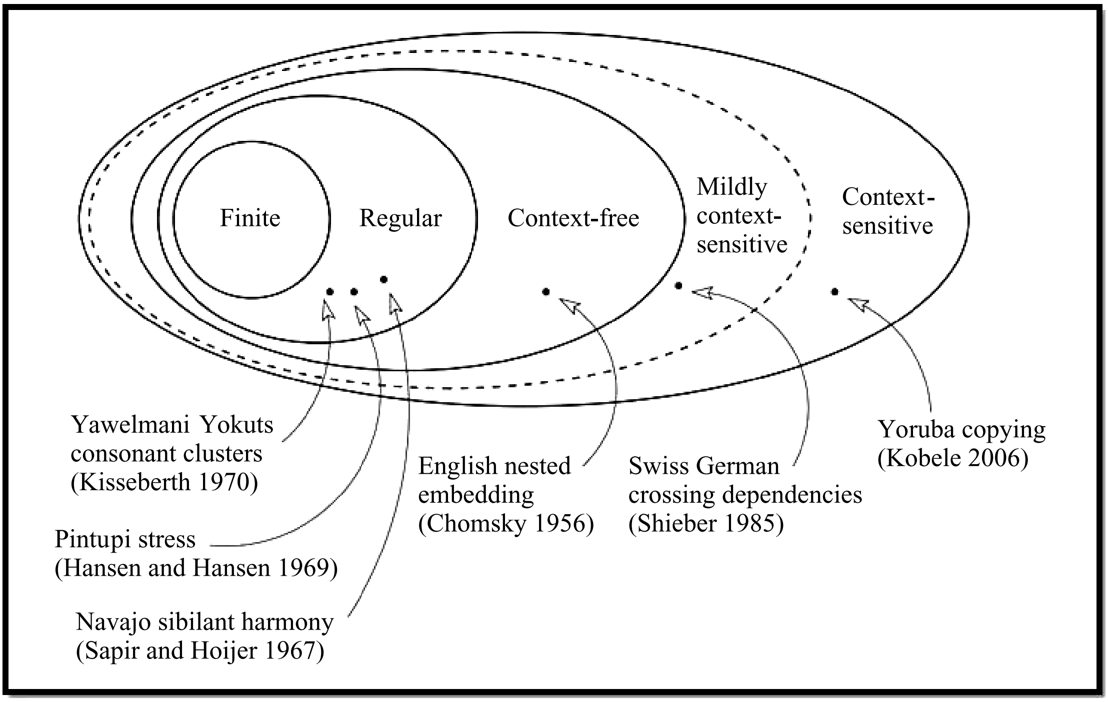

Figure 1: The Chomsky Hierarchy. Various features of natural language occupy different regions of the hierarchy. This Figure was reproduced from Figure 1 in Heinz (2010:p. 634) with permission.

within the regular region. These patterns are Strictly-Local (SL), Strictly-Piecewise (SP), and Non-Counting patterns (NC) (McNaughton & Papert, 1971; Heinz, 2010; Rogers et al., 2010; Rogers & Pullum, 2011; Heinz & Rogers, 2013).

A strictly k-Local (SL_k) pattern is one where the well-formedness of a string is determined by whether or not its contiguous substrings of length k are well-formed. That is, SL languages only make distinctions on the basis of contiguous substrings up to some length k (called k-factors). A strictly k-Piecewise (SP_k) pattern, on the other hand, is one where well-formedness of a string is determined by its subsequences of length k, that is, if the set of subsequences in the string in question is a subset of the set of subsequences allowed by the grammar, the string is well-formed; otherwise, it is not. Thus, subsequences are not necessarily contiguous and the patterns they describe contain long-distance dependencies. In the regular region, apart from SL and SP, there are also other regular patterns which are neither SL nor SP. These patterns can be collapsed under the Non-Counting patterns. A pattern is Non-Counting if there is a number n such that for all strings u, v, w, if $uv^n w$ occurs in L, then $uv^{n+1}w$ occurs in L as well (McNaughton & Papert, 1971).

Figure 2 below presents a schematized representation of the above constraints and classifies two attested and one unattested phonological constraints: Nasal Place Assimilation, which is an attested local dependency pattern; Sibilant Harmony (SH), which is an attested long-distance dependency pattern; and First-Last Assimilation (FL), which is an unattested, non-SL, non-SP long-distance dependency pattern (for details about SH and FL patterns, see section 1.2 below).

In contrast to the Non-Counting patterns, the SL and SP classes include almost all natural language phonotactic patterns (Heinz, 2010); that is, no language has a phonotactic pattern like FL. In this respect, Heinz's (2010) strong Subregular Hypothesis is supported by the typology of phonotactic patterns and predicts that humans' phonological pattern detectors can only learn phonotactic constraints that are SL or SP. If this is the case, then the absence of patterns such as FL from the natural languages can be explained; namely, the regularities present in patterns of FL cannot be extracted by humans' phonological learning mechanism. The weaker version of the Subregular Hypothesis claims that patterns with specific subregular computational properties are privileged with respect to learnability.

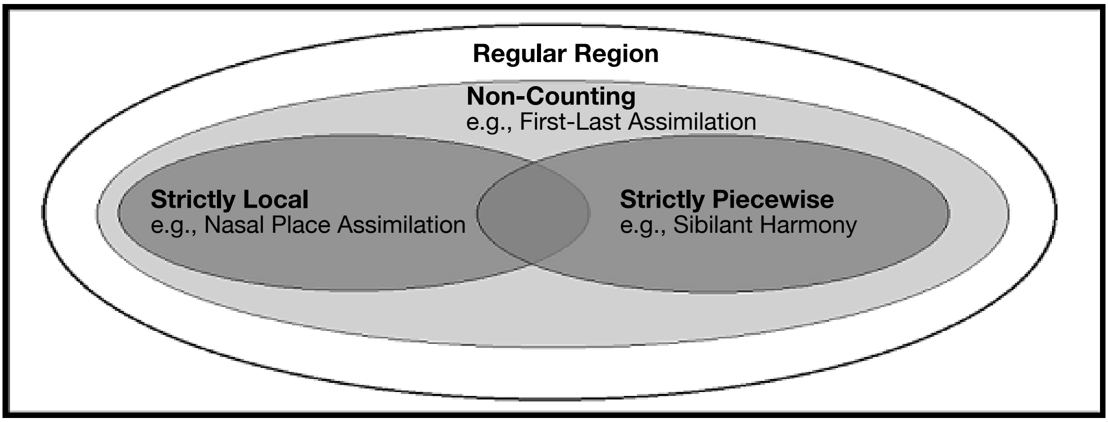

Figure 2: Subregular Hierarchy. SL, SP and Non-Counting are all in the regular region.

1.2. Behavioral evidence for Subregular Hypothesis

The learnability of SL patterns has been studied by Aslin et al. (1998); Dell et al. (2000); Onnis et al. (2005); Chambers et al. (2003); Goldrick (2004). The learnability of SP patterns has been studied by Pycha et al. (2003); Wilson (2003); Newport & Aslin (2004); Onnis et al. (2005); Finley & Badecker (2009a,b); Finley (2011, 2012); Koo & Callahan (2012). Results of these artificial language studies show SL and SP patterns are readily learned in laboratory settings.

There is, however, a further question to be asked: what about the other patterns that are subregular but neither SL nor SP? Lai (2015) provided experimental evidence for the Subregular Hypothesis by comparing the learnability of two long distance harmony patterns. Sibilant Harmony (SH), which is an attested long distance harmony pattern in Navajo (sibilants in a well-formed word have to agree in anteriority) (Sapir & Hoijer, 1967), belongs to SP region (Heinz, 2010). Hypothetical words such as [sokosos] and [ʃokoʃoʃ] are grammatical because in both words each of the three sibilants has the same anteriority feature; whereas *[sokosoʃ] or *[ʃokosoʃ] are not grammatical because both words contain disagreeing sibilants in terms of anteriority. On the other hand, First-Last Assimilation (FL), which is an unattested long-distance harmony pattern (allowing disharmonic intervening segments so long as the first and last sounds are harmonic), belongs to the Non-Counting region (Heinz, 2010).[1] For example, [sokoʃos] and [ʃokosoʃ] are following the rule since in each word first and last sibilants agree in anteriority; whereas *[sokosoʃ] or *[ʃokoʃos] are violating the rule because first and last sibilants in each word don't agree in anteriority.

Lai (2015) employed an artificial grammar learning paradigm to test whether SH or FL can be learned by human subjects. Three experimental groups were tested (SH, FL and control); each of them underwent two phases: a training phase and a testing phase. The SH group was trained by listening to words that conformed to SH grammar, and the FL group was trained by listening to words that conformed to FL grammar. The control group received no training. In the test, two-alternative forced choice (2AFC) was used in that participants had to judge whether the first word or the second word of a presented pair was more likely to belong to the artificial language they had just heard during the training. The results are consistent with the hypothesis that the phonological learner is restricted by subregular constraints; namely, FL was NOT learned readily but SH was. Therefore, the study concluded that a regular pattern outside the SP or SL regions is not as easily learnable as an SP one.

[1] FL specifically belongs to the Locally Testable (LT) class which is defined with a formula in propositional logic and under the Non-Counting region. Readers are referred to Heinz (forthcoming) for more information about the subregular class of stringsets.

1.3. The current study

Lai (2015) showed that when humans were exposed to words conforming to an SP pattern, they detected it and were able to extract a rule for the pattern. This can be explained if SH lies inside the hypothesis space of humans' phonological pattern detectors, contrary to FL.

The aim of the current research is to replicate Lai's learnability results with a different test design: an oddball paradigm; and with a different measure: the sensitivity index (d') (Signal Detection Theory (SDT); (Green & Swets, 1966; Macmillan & Creelman, 2004)). More specifically, this research is testing whether behavioral learning of artificial but natural-language-possible phonotactic rule types versus unnatural ones will instantly lead to observable real-time phonotactic parsing predictions. In this respect, measurements of SDT will be introduced as data to answer the question of whether phonotactic rules can be acquired in the laboratory.

I assume that once a learner has extracted a rule from a set of training data, the processing system implements the rule and immediately starts to generate predictions during real-time phonological parsing: new and subsequent input should conform to the rule. Thus, acquisition of a rule should be measurable with d' when those predictions are not met and an error signal is generated. Learning of language-impossible phonotactic rules should be reflected in a lack of predictions at the phonological processing level. I can test the hypotheses about which grammars are learnable and which are unlearnable by testing which type of rules elicit prediction-error related responses.

2. Materials and methods

2.1. Participants

A total of 72 University of Delaware students were recruited as subjects and provided written consent in the experiment. Each subject received course credit for participation. 66 of the 72 subjects were females and 6 were males (this imbalance arises from the fact that the population I sampled from was overrepresented with women). Six subjects were left-handed, but I did not exclude left-handers, as most left-handed people have left-lateralized language function. The mean age was 22 (SD = 4.32, range = 18 to 31). None of the subjects reported a history of hearing loss or speech/language impairments, and all reported having English as their first and only language.

2.2. Apparatus and procedure

The programming software used in the experiment was E-Prime Professional software v. 2.0.10.356, running on a Dell desktop PC. The experiment was conducted inside a single-walled electrically shielded sound booth in the Experimental Psycholinguistics Lab at the University of Delaware. The presentation of sound stimuli was executed with two free field speakers placed in front of the subjects at comfortable listening volume; and visual input was delivered through an LCD display placed on a table in front of the subjects. The PST Serial Response box was used for recording behavioral responses.

The study consisted of three experimental conditions. The first one tests the learnability of the Sibilant Harmony (SH) rule, an attested long distance harmony pattern that belongs to a learnable subregular region (Heinz, 2010). The second one tests whether the unattested First-Last Assimilation (FL) rule will be learned, again a long distance harmony pattern that belongs to a subregular region hypothesized to be unlearnable (or difficult to learn according to the weak subregular hypothesis) (Heinz, 2010). The third condition tests the learnability of the intensive First-Last Assimilation (IFL) [2], which is similar to the FL condition except certain training items are omitted to emphasize others.

The procedure for these experimental conditions consisted of two phases: a training phase and a testing phase. During the training phase, participants listened to harmonic words (according to the experimental condition they are in) and were instructed to repeat each word orally once they heard it. The training contained 200 tokens (40 words x 5 repetitions) and the duration was approximately 15 minutes. Therefore, the training phase was an exact replication of the Lai (2015). The training was followed by a testing phase in which the oddball paradigm, where a deviant stimulus infrequently appears among

[2] Intensive FL specifically belongs to the Tier-Based Strictly Local (TSL) class which is a specific generalization of Strictly Local class. Readers are referred to Heinz (forthcoming) for more information about the subregular class of stringsets.

repeated occurrences of a standard stimulus [3], was executed. Participants were presented with words in a continuous string and were asked to judge whether a word violates the phonotactic pattern or the rule system of the artificial language they had just learned during training (even if they could not articulate the rule). The task for the participant was to find the deviant stimuli (disharmonic words) by pressing a response box button to indicate his/her decision. [4]

Each participant was presented with a total of 528 trials in the testing phase: 432 words (72 words x 6 repetitions) as harmonic and 96 (48 words x 2 repetitions) words as disharmonic words. The test phase was divided into two blocks but each of which were the same in terms of the standards and deviants. The stimuli were delivered continuously, with a random number (between 3 and 7) of standards between each deviant. The 264 trials in each block consisted of 48 deviants (18%) and 216 standards (82%). The total duration for both training and testing was about 50 minutes.

2.3. Stimuli and design

Since I am partially replicating Lai (2015), the same stimuli were used. All of the training and test stimuli had threes syllables in the form of "*CV.CV.CVC*". The consonants in the alphabet of the language were only [k,s,ʃ], and the vowels were [a,ɛ,ɔ,i,u]. Half of the training stimuli had a stop [k] as the second consonant and the other half had it as the third consonant. Therefore, the first and last consonants were always sibilants. In the testing phase, disharmonic words for each condition were in four different forms and each form is represented with 12 words; (i) the disharmonic sibilant was [s] and it was in the middle (e.g., *SH2-s), (ii) the disharmonic sibilant was [ʃ] and it was in the middle (e.g., *SH2-ʃ), (iii) the disharmonic sibilant was [s] and it was in the end (e.g., *SH3-s), and (iv) the disharmonic sibilant was [ʃ] and it was in the end (e.g., *SH3-ʃ). All of the words which had a disharmonic sibilant in the end ([s.s.ʃ] or [ʃ..ʃ..s]) had a stop (k) as the second consonant. And half of the words which had a disharmonic sibilant in the middle ([s..ʃ..s] or [ʃ..s..ʃ]) had a stop (k) as the second consonant and the other half as the third consonant. Table 1 summarizes the types of training and test stimuli used. Lai (2015) reports that the stimuli used in the experiment were natural speech. The mean duration of stimuli was 1013 ms; the longest stimuli was 1251 ms and the shortest was 884 ms.

	Conditions					
Sibilant Tier	SH	*SH	FL	*FL	IFL	*IFL
[s..s..s]	[s..s..s]	None	[s..s..s]	None	None	None
[ʃ..ʃ..ʃ]	[ʃ..ʃ..ʃ]	None	[ʃ..ʃ..ʃ]	None	None	None
[ʃ..s..ʃ]	None	[ʃ..s..ʃ] (*SH2-s)	[ʃ..s..ʃ]	None	[ʃ..s..ʃ]	None
[s..ʃ..s]	None	[s..ʃ..s] (*SH2-ʃ)	[s..ʃ..s]	None	[s..ʃ..s]	None
[ʃ..ʃ..s]	None	[ʃ..ʃ..s] (*SH3-s)	None	[ʃ..ʃ..s] (*FL3a-s)	None	[ʃ..ʃ..s] (*FL3a-s)
[s..s..ʃ]	None	[s..s..ʃ] (*SH3-ʃ)	None	[s..s..ʃ] (*FL3a-ʃ)	None	[s..s..ʃ] (*FL3a-ʃ)
[ʃ..s..s]	None	None	None	[ʃ..s..s] (*FL3b-s)	None	[ʃ..s..s] (*FL3b-s)
[s..ʃ..ʃ]	None	None	None	[s..ʃ..ʃ] (*FL3b-ʃ)	None	[s..ʃ..ʃ] (*FL3b-ʃ)

Table 1: SH, FL and IFL shows the harmonic stimuli patterns used in the training phase and *SH, *FL and *IFL shows the disharmonic stimuli patterns used in the testing phase.

2.4. Data recording and analysis

In the test phase, button presses made by participants to deviant stimuli were recorded. When the signal (disharmonic words) was present and the participant detected it and reported seeing it, it was counted as a hit. The proportion of hits was calculated as

[3] Standards are the words following the pattern (SH, FL or IFL) and the deviants are the words violating the pattern (*SH, *FL or *IFL).

[4] No explicit feedback was given to participants during test phase. The reason of this is to ensure that the learning context must be as close to a natural language acquisition context as possible.

(1) $$P(hits) = \frac{Nhits}{Ndeviants}$$

with N being the number of times that the event was observed. When the signal was absent and the participant thought s/he saw something and reported it (when standard stimuli (e.g., sibilant harmonic word) was presented and the participant reported it as a deviant), it was counted as false alarm. The proportion of false alarms was calculated as

(2) $$P(falsealarms) = \frac{Nfalsealarms}{Nstandards}$$

The sensitivity index d' was then derived from the hit and false alarm rates according to signal detection theory (SDT); (Green & Swets, 1966; Macmillan & Creelman, 2004). The sensitivity index was calculated as

(3) $$d' = Z(Phits) - Z(Pfalsealamrs)$$

where P hits is the hit rate, P false alarms is the false alarm rate and Z is the z-score [5] for that particular probability. The bias measure (C) which is participants' bias towards finding a signal was also derived from the hit and false alarm rates according to SDT. The bias measure C was calculated as

(4) $$P(falsealarms) = \frac{Z(Phits) + Z(Pfalsealarms)}{2}$$

d' shows the threshold for signal strength and results higher than 0 show that sensitivity is better than chance level. Thus, in the context of our study positive d' means the rule is learned and the disharmonic words were discriminated. Likewise, C shows the bias towards reporting the signal or not; and negative bias indicates that there is bias towards no signal which means, in the context of this study, the rule is learned. [6]

Finally, d' and C values were compared across four deviant patterns for each experimental condition (see Table 1 above) in a repeated-measures analysis of variance (ANOVA) with the two factors: phoneme (two levels: [s] and [ʃ]) and either violation point (where the violating phoneme occurs in a word, two levels: middle and end) (for the SH condition) or violation type (which type the stimuli is, two levels: type a and b) (for the FL and IFL conditions).

3. Results

Behavioral d' results for the SH condition showed that deviants were detected with a mean sensitivity of $1.547(SD = 1.68)$, $F(1, 23) = 20.214, p = 0.001$, observed power $(alpha = .05) = 0.99$, as shown in Figure 3, (left panel); and biased at a mean rate of $-0.485(SD = 0.49)$, as illustrated in Figure 3, (right panel). As for the within subject comparisons, deviants were detected with a mean sensitivity of 1.407 (*SH2-s), 1.364 (*SH2-ʃ), 1.546 (*SH3-s), and 1.870 (*SH3-ʃ) (Figure 3, (left panel)). ANOVA results showed that sensitivity index (d') was not significantly affected by the violation point, $F(1, 23) = 2.84, p = .106$; and not significantly affected by the phoneme, $F(1, 23) = .633, p = .434$. Also, there was no interaction between violation point and phoneme, $F(1, 23) = .771, p = .389$; and none of the pair-wise comparisons were significant (all p values $> .05$). Bias (C) results for the SH condition, on the other hand, showed that deviants were biased at a mean rate of $-.696$ (*SH2-s), $-.498$ (*SH2-ʃ),

[5] In order to avoid infinite values in the z-scores, hit and false alarm rates were adjusted to 0.000001 when they were actually 0 and to 0.999999 when they were actually 1.

[6] Due to the nature of the oddball paradigm, where deviants are infrequent, we will always see negative bias; therefore, bias measure on its own may not be meaningful in our study.

$-.635$ (*SH3-s), and $-.111$ (*SH3-ʃ) (Figure 3, (right panel)). ANOVA results showed that the bias was significantly affected by the violation point, $F(1, 23) = 10.080, p = .004$; and significantly affected by the phoneme, $F(1, 23) = 5.851, p = .024$. However, there was no interaction between violation point and phoneme, $F(1, 23) = 2.901, p = .102$. Pair-wise comparisons revealed significant differences between *SH3-s vs. *SH3-ʃ ($p = .021$) and between *SH2-ʃ vs. *SH3-ʃ ($p = .011$), other pair-wise comparisons were not significant (all p values $> .05$).

As for the FL condition, deviants were detected with a mean sensitivity of $0.187 (SD = 0.31)$, $F(1, 23) = 8.968, p = 0.006$, observed power $(alpha = .05) = 0.82$, as shown in Figure 4, (left panel); and biased at a mean rate of $-0.777 (SD = 0.41)$, as illustrated in Figure 4, (right panel). Within subject comparisons show that deviants' mean sensitivities were 0.197 (*FL3a-s), 0.219 (*FL3a-ʃ), 0.268 (*FL3b-s), and 0.065 (*FL3b-ʃ) (Figure 4, (left panel)). ANOVA results showed that sensitivity index (d') was not significantly affected by the violation type (a or b), $F(1, 23) = 0.087, p = .77$; and by the phoneme (s or ʃ), $F(1, 23) = .411, p = .528$. Also, there was no interaction between violation type and phoneme, $F(1, 23) = 1.073, p = .310$; and none of the pair-wise comparisons were significant (all p values $> .05$). Bias (C) results for the FL condition showed that deviants were biased at a mean rate of $-.695$ (*FL3a-s), $-.958$ (*FL3a-ʃ), $-.752$ (*FL3b-s), and $-.703$ (*FL3b-ʃ). ANOVA results showed that the bias was not significantly affected by the violation type and phoneme (both p values $> .05$). However, there was a significant interaction between the two, $F(1, 23) = 7.81, p = .010$, observed power $(alpha = .05) = 0.76$, (Figure 4, (right panel)).

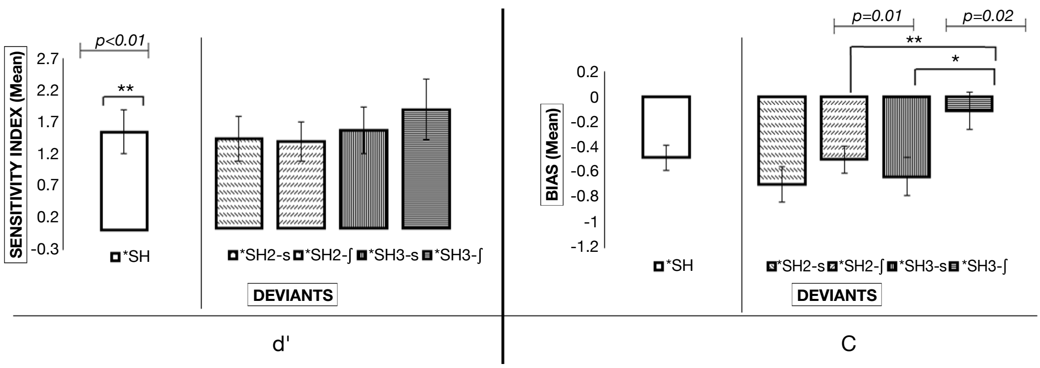

Figure 3: SH Condition: Group averages of sensitivity index rates of deviants (left panel), and bias rates of deviants (right panel).

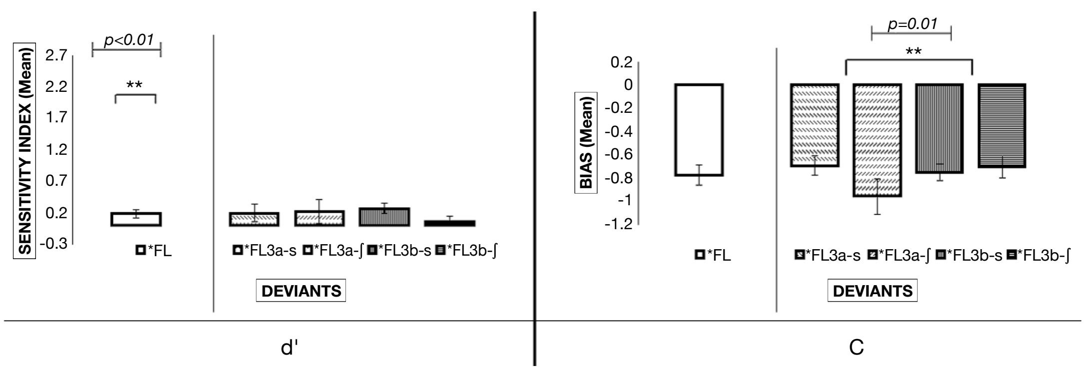

Figure 4: FL Condition: Group averages of sensitivity index rates of deviants (left panel), and bias rates of deviants (right panel).

In the IFL condition, deviants were detected with a mean sensitivity of $0.213 (SD = 0.21)$, $F(1, 23) = 25.544, p = 0.001$, observed power $(alpha = .05) = 0.99$, as shown in Figure 5, (left panel); and biased at a mean rate of $-0.668 (SD = 0.40)$, as illustrated in Figure 5, (right panel). Within subject comparisons show that deviants' mean sensitivities are 0.423 (*FL3a-s), 0.287 (*FL3a-ʃ), 0.046

(*FL3b-s), and 0.097 (*FL3b-ʃ) (Figure 5, (left panel)). ANOVA results showed that the sensitivity index (d') was not significantly affected by the violation type or by the phoneme, and no interaction between the two (all p values $> .05$). Bias (C) results for IFL condition showed that deviants were biased at a mean rate of $-.612$ (*FL3a-s), $-.704$ (*FL3a-ʃ), $-.600$ (*FL3b-s), and $-.755$ (*FL3b-ʃ) (Figure 5, (right panel)). ANOVA results showed that bias was not significantly affected by the violation type or by the phoneme, and no interaction between the two (all p values $> .05$).

Finally, when the condition as a between subject variable was added to the design, a significant main effect of condition was revealed, $F(2, 69) = 14.608, p = 0.001$, observed power $(alpha = .05) = 0.99$.

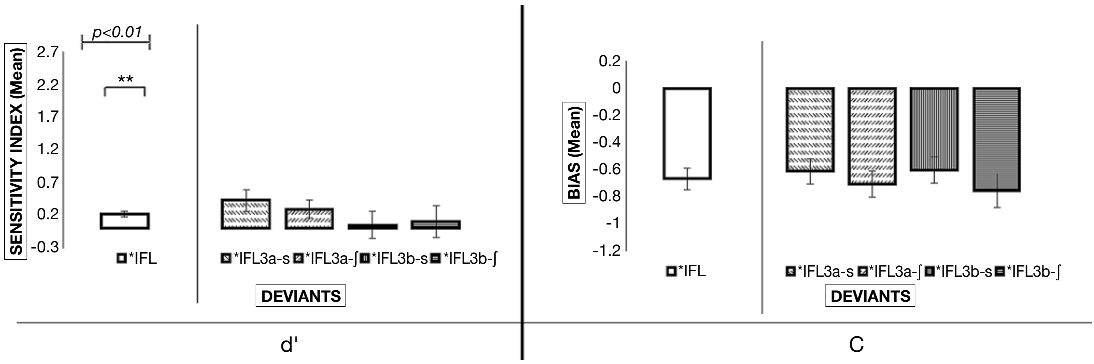

Figure 5: IFL Condition: Group averages of sensitivity index rates of deviants (left panel), and bias rates of deviants (right panel).

However, there was no significant difference between the FL and IFL conditions, $F(1, 46) = 0.119, p = 0.73$, (Figure 6, (left panel)).

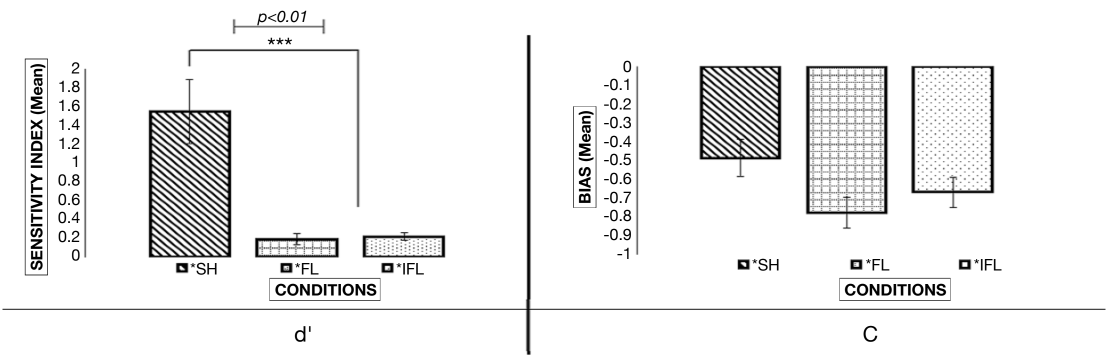

Figure 6: All Conditions: Group averages of sensitivity index rates of deviants (left panel), and bias rates of deviants (right panel).

4. Discussion

By manipulating and violating the participants' auditory expectations at two distinct positions (or types) with two distinct phonemes, I aimed to obtain direct behavioral evidence which would support an active and predictive system underlying the brain's response to auditory stimuli.

The results above showed that in each condition participants showed sensitivity to the deviant stimulus patterns. In the SH condition, all the deviants were detected with a mean sensitivity higher than zero and biased at a negative mean rate; thus d' for disharmonic words was better than chance level which shows that participants learned the rule. Although disharmonic /ʃ/ at the end of a word was detected with a higher mean than the others, there was no effect of phoneme or where the violation happens in a word on the sensitivity index. Furthermore, the results showed that participants were conservative and biased to report no signal for the disharmonic words. Descriptive statistics for bias measure suggests that disharmonic /ʃ/ at the end of a word made a significant difference. The reason for this could be the special status of word edges in phonology as discussed in Lai (2015); sounds at these positions become more perceptually salient. Pair-wise comparisons also showed that disharmonic /ʃ/ when occurring word finally was biased significantly differently. Although previous research showed that spectral peak is consistently measured higher for alveolar fricatives [s,z] than for palatal fricatives [ʃ,ʒ] (Soli, 1981), our results showed the reverse. Also, the difference between /s/ and /ʃ/ can be attributed to the frication itself, rather than to the surrounding vowel transitions (Harris, 1958; Martin & Peperkamp, 2011). Nevertheless, as I pointed out above, since this study used the oddball paradigm in which the deviants were infrequent, negative bias was not unexpected; thus, any conclusion based on the bias measure can be fallacious within this context.

The asymmetry shown in the SH condition: positive d' and negative bias persists in the other two experimental conditions too, FL and IFL. Since participants used those three rules to judge the grammaticality of the incoming stimuli, it can be concluded that the rules were extracted and active at the behavioral level. However, participants in the SH condition were significantly more sensitive to the oddballs, implying unattested FL patterns are clearly more difficult to learn than the attested pattern.

The fact that unattested FL patterns were also learnable in the sense that their d' values are higher than chance level seems to contradict Lai (2015). In the same way, the sensitivity levels in the FL and IFL conditions appear to falsify the strong *Subregular Hypothesis* that they are not learnable. Notwithstanding, learning in the laboratory is not the same as learning naturally. It remains plausible that laboratory subjects brought domain-general learning to bear which made FL and IFL patterns learning possible, but the SH pattern was much more readily learned because it was detectable by specific phonological learning mechanisms.

In a similar vein, a reviewer pointed out that the learnability of unattested FL patterns can be explained as follows: learnability of the FL pattern depends on domain-general cognition whereas SH pattern depends on phonology. In this sense, *Subregular Hypothesis* is an example of domain specific constraint on induction. I.e., it is hypothesized to constrain detection of patterns in human languages, but not necessarily constrain detection of similar patterns in stimuli that are not attested. The domain specific hypothesis is that unattested patterns get channeled to domain general learning mechanisms. On the other hand, patterns that are attested in human languages exhibit constrained learning, because they are channeled to language-specific learning modules. We, as a future study, will test this claim by using non-linguistic auditory stimuli to see whether non-linguistic stimulus patterns that can be described by the same grammars as SH and FL are linguistically constrained even when the stimuli do not bear any resemblance to linguistic forms.

5. Conclusion

In this paper, I compared the relative learnability of two long-distance harmony patterns (Sibilant Harmony vs. First-Last Assimilation) that differ typologically (attested vs. unattested) and computationally (Strictly Piecewise vs. Non-Counting). I tried to outline an experimental framework for how abstract rules get translated into processing routines that generate real-time phonotactic predictions during auditory processing, and how this processing system is instrumental in language acquisition. I presented experimental results showing that adult learners prefer some phonological patterns or distributions over the others. These results substantiate that a weaker version of the Subregular Hypothesis is active during real-time phonological parsing and to some extent constrains the learnability of specific phonotactic patterns. However, the fact that the unattested patterns (FL and IFL) are still learnable, even if they are harder, given the strong Subregular Hypothesis predicts they can't be learned at all, reveals that the learnability constraints put forward by the strong Subregular Hypothesis should be attenuated.

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