Learnable vs. Unlearnable Harmony Patterns

Regine Lai (rlai@udel.edu)
University of Delaware

Hypothesis This study hypothesizes that some logically possible phonological patterns are unattested because of limitations on how humans abstract regularities from speech.

Background Virtually all phonological patterns are *regular* (Kaplan and Kay, 1994); i.e., describable with finite-state automata. However, many regular patterns are not phonological. Heinz (2007, 2010) shows that phonotactic patterns belong to the "Strictly Local" (SL) and "Strictly Piecewise" (SP) *subregular* regions. If these *subregular* boundaries are psychologically real, then logically possible, regular sound patterns outside these regions ought not be learnable by humans. One example of a regular, sound pattern that is not found in any natural languages to our knowledge is long-distance assimilation of the first and last sounds of a word. This first-last assimilation (FL) requires the first segment and the last segment to be harmonic, but permits any number of disharmonic intervening segments. This is substantially different from well-documented, long-distance harmony patterns (Hansson, 2001; Rose & Walker, 2004), because the latter prohibits disharmonic intervening segments. We illustrate the difference with concrete examples; consider first the case of sibilant harmony (SH), which is documented in Navajo (Sapir and Hoijer 1967). Navajo requires sibilants in well-formed words to agree in anteriority. Hypothetical words [sototos] and [ʃototoʃ] are both grammatical since the two sibilants in each word agree in anteriority, but [ʃototos] and [sototoʃ] are both ungrammatical due to the difference in anteriority in the two sibilants within each word.

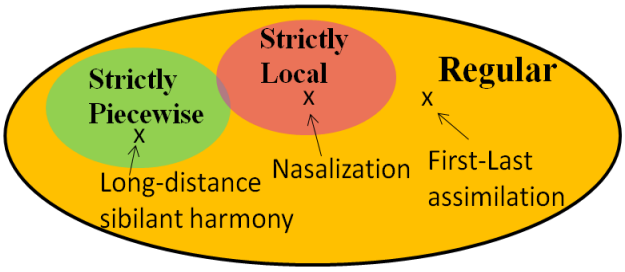

Figure 1 A schematized representation of subregular and non-regular boundaries

On the other hand, consider a first-last assimilation rule that involves sibilants. In this pattern, [sototos] and [ʃototoʃ] are also well-formed words, and [ʃototos] and [sototoʃ] are ill-formed, but for a different reason: [sototos] and [ʃototoʃ] are well-formed because the sibilants *which are in the initial and last position of the word* agree in anteriority. The strings, [ʃototos] and [sototoʃ] are not well-formed because the sibilants in the first and last position of the word do not agree in anteriority. Note that there are no words that are well-formed according to SH, but not FL.

From a linguistic and cognitive perspective, FL seems plausible not only because long-distance dependencies between sounds are attested in natural language, but also because word edges have special status in phonology (Beckman, 1998; Endress et al., 2009). In this light, FL is not very bizarre. If the learning mechanism for phonology can only learn SL and SP languages as Heinz (2010) suggests, then the absence of FL from the attested languages can be explained: they are not humanly learnable sound patterns.

Methodology The artificial language learning paradigm (e.g. Folia et al, 2008; Gómez & Gerken, 2000; Petersson et al., 2004; Reber, 1967) was employed. Subjects were exposed to stimuli generated by either a SH or FL grammar according to the experimental condition. In the testing phase, two stimuli were presented at each trial, and subjects were asked to choose the one that was more likely to belong to the language they heard during training. A control condition (no training) was conducted to obtain the baseline of performance.

Sixty-six native American-English monolingual speaking adults were recruited. The experiment took place in a soundproof booth in the Phonetics and Phonology laboratory of University of Delaware. Subjects engaged in an artificial language learning task consisting of a training (learning) phase, and a testing phase. During the training phase, subjects listened to words that conform to a specific pattern (the pattern varied across conditions), and were instructed to repeat each word orally after it was presented. The training data contained 200 tokens (40 words x 5 repetitions) and the duration was approximately 15 minutes. A testing phase followed once the training stage was completed. Subjects were presented with words in pairs, and were asked to judge whether the first word or the second word within a pair was more likely to belong to the artificial language they just heard during the training phase. There were 48 pairs of test items in total and each subject took about 7 minutes to complete this phase. The total duration for each experiment was about 20-30 minutes. In the control condition, no training was given. Subjects were given the test only. All subjects, regardless of which condition they were in, were given the same test.

All training and testing items were trisyllabic, with the structure of CV.CV.CVC. The consonants [k, s, ʃ] and vowels [a, ɛ, i, ɔ, u] were used to create these syllables. The training stimuli included only legal strings that were consistent with the particular grammar tested in each condition. In the SH condition, only words that conformed to SH e.g. [s…s…s] or [ʃ…ʃ…ʃ] were included. In the FL condition, only words that conformed to FL were included, e.g. [s…s…s] or [s…ʃ…s]. In the control condition, no training was given to the subjects.

The test stimuli were identical across all conditions. One-third of the test items were words that contained disagreeing sibilants in the first and the last consonants (e.g. [s…s…ʃ]), and these were words that neither conformed to SH nor FL grammar (*FL/*SH). Another third of the test items were words that contained agreeing sibilants throughout the word (e.g. [s…s…s], and these were words that conformed to SH and FL (FL/SH). Lastly, the remaining one third were words that contained agreeing sibilants only in the first and last consonants (e.g. [s…ʃ…s]), and these words only conformed to FL (FL/*SH). The fourth logically possible type [*FL/SH] were not present because all stimuli that conform to SH also conform to FL.

These 3 types of test stimuli were pitted against each other and generated 3 types of pairings:

a) FL/*SH vs. *FL/*SH (also included*FL/*SH vs. FL/*SH); b) FL/SH vs. *FL/*SH (also included*FL/*SH vs. FL/SH); c) FL/*SH vs. FL/SH (also included FL/SH vs. FL/*SH).

Results Control subjects, who did not receive any training, did not perform significantly different from chance level (0.5). In other words, when they were asked if they preferred any particular type of word, they made a random choice. This indicates that English speaking subjects did not have any inherent preference for any word type used in the experiment, and any effect we shown by experimental subjects should be brought about by the training.

The SH group's results were different. When they were given the pairing of [*FL/*SH] vs. [FL/*SH], they did not perform significantly different from chance ($t(21)= -.428$, $p = .673$). This follows the prediction of learning SH successfully as neither choice within this pairing is consistent with SH. For the second type of pairing, SH subjects' rate of choosing [FL/SH] when they were given the choice of [*FL/*SH] vs. [FL/SH] was significantly higher than 0.5 ($t(21)=3.322$, $p = .002$). This is also in line with the assumption that SH is learned successfully as [FL/SH] is consistent with SH but [*FL/*SH] is not. Lastly, the rate of choosing [FL/SH] when subjects were given the choice of [FL/*SH] vs. [FL/SH] was also significantly higher than chance ($t(21)=1.817$, $p = .042$). Subjects were able to pick out the items that conform to SH significantly more than the items that do not. Combining the results from all three different

pairings, we can conclude that SH subjects who were exposed to training items that conformed to SH were able to internalize SH. In other words, SH was learned.

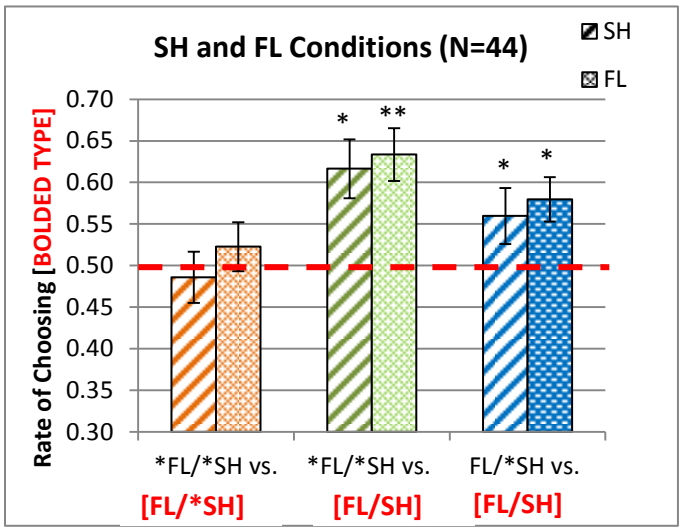

Figure 2 SH and FL conditions results. The *y*-axis is the rates of choosing the **Bolded Type** within each pairing, and each bar stands for different pairing (see labels on *x*-axis)

The FL results were surprising. Not only was FL not learned, but FL subjects' performance was very similar to the SH subjects'. When they were given the pairing of [*FL/*SH] vs. [FL/*SH], they did not perform significantly different from chance ($t(21)=.830.$, $p=.208$.). If FL is learned successfully, the rate of choosing [FL/*SH] should be above chance level as [FL/*SH] conforms to FL but [*FL/*SH] does not. For the second type of pairing, FL subjects' rate of choosing [FL/SH] when they were given the choice of [*FL/*SH] vs. [FL/SH] was significantly higher than 0.5 ($t(21)= 4.274$, $p < .001$).

This is in line with the assumption that FL is learned successfully. [FL/SH] is consistent with FL but [*FL/*SH] is not. Lastly, the rate of choosing [FL/SH] when subjects were given the choice of [FL/*SH] vs. [FL/SH] was also significantly higher than chance ($t(21)=3.022$, $p = .003$). This is also different from the prediction made by FL grammar, as both items conform to FL, hence, if FL subjects internalized FL grammar, they should perform at chance. FL subjects chose items that conformed to SH significantly more than items that do not, but failed to choose items that only conformed to FL. Combining the results from all three different pairing, we can conclude that FL subjects who were exposed to training items that conformed to FL were unable to internalize FL, but instead, they seem to have internalized SH grammar. These results were surprising because the training items included those that did not conform to SH e.g. [s...ʃ…s] and [ʃ…s…ʃ], yet, they seem to ignore these training items, and chose to accept SH grammar.

This could be the case that subjects were heavily biased towards learning SH, and the presence of stimuli that conform to both SH and FL had led subjects to falsely assume the SH grammar. In light of this assumption, we conducted an additional experiment to test the learnability of FL if these ambiguous stimuli were replaced by words that only conformed to FL.

An additional 22 subjects were recruited. The FL training stimuli were constructed in the same manner as the other two experimental conditions. Words that conform to both SH and FL, e.g. [s…s…s] and [ʃ…ʃ…ʃ] were replaced by words that only conform to FL e.g. [s…ʃ…s] and [ʃ…s…ʃ]. Instead of 4 types of training stimuli, only 2 were used in the Intensive FL condition. Test items remained the same in this condition.

The results of this condition were significantly different from the FL condition. When the Intensive FL subjects were given the pairing of [*FL/*SH] vs. [FL/*SH], they chose [FL/*SH] significantly higher than chance level ($t(21) = 2.374$, $p = .013$). If FL is learned successfully, the rate of choosing [FL/*SH] should be above chance level as [FL/*SH] conforms to FL but [*FL/*SH] does not. For the second type of pairing, intensive FL subjects' rate of choosing [FL/SH] when they were given the choice of [*FL/*SH] vs. [FL/SH] was significantly lower than 0.5 ($t(21)= -2.772$, $p =.011$), which means they chose the items that were inconsistent with

both FL and SH more often. This is different from the assumption that FL is learned successfully as [FL/SH] is consistent with FL but [*FL/*SH] is not. Lastly, the rate of choosing [FL/SH] when subjects were given the choice of [FL/*SH] vs. [FL/SH] was also significantly lower than chance ($t(21)= -4.439$, $p \leq .001$). This is also different from the prediction made by FL grammar, as both items conform to FL, therefore, if Intensive FL subjects internalized FL grammar, they should perform at chance. Combining the results from all three different pairings, we can conclude that Intensive FL subjects chose the items that conformed only to FL but not to SH. This is, in a way consistent with the training grammar they were exposed to as they were only given words that conformed to FL but not SH. This means Intensive FL subjects internalized a restricted version of FL i.e. the middle sibilant had to disagree with the first and the last sibilants. This pattern seems to coincide with sibilant disharmony which requires neighboring sibilants to be disharmonic to each other, and this type of pattern falls into the range of grammars that can be described by SP. However, if we consider the second pairing carefully ([*FL/*SH] vs. [FL/SH]), as neither of these items are totally disharmonic. Intensive FL subjects chose [*FL/*SH] more often than [FL/SH] probably because [*FL/*SH] is *more* disharmonic than [FL/SH]. Nonetheless, Intensive FL subjects definitely failed to internalize the FL grammar that was intended in this study, and together with the SH and FL condition results obtained from a carefully controlled experimental setting, FL is harder to learn than SH.

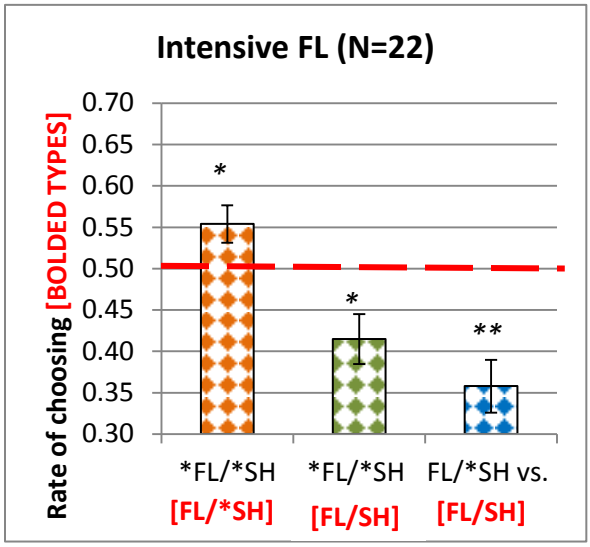

Figure 3 Intensive FL condition results. The *y*-axis is the rates of choosing the **Bolded Type** within each pairing, and each bar stands for different pairing (see labels on *x*-axis)

Conclusion Subjects in the SH condition internalized the SH pattern, while subjects in the FL and Intensive FL conditions did not learn FL. These results suggest that FL, an unattested pattern is harder to learn than an attested pattern SH. These results are consistent with the hypothesis that the fact that FL is not present in natural language phonology is due to human's restrictions in abstracting phonological patterns that are not strictly local or strictly piecewise.

Selected References

Beckman, J. (1998). Positional faithfulness. Ph.D dissertation, University of Massachusetts Amherst.

Gómez, R. L., & Gerken, L. A. (2000). Infant artificial language learning and language acquisition. *Trends in Cognitive Sciences*, 4, 178–186

Heinz, J. (2007). The inductive learning of phonotactic patterns. PhD Thesis, UCLA.

Heinz, J. (2010). Learning long-distance phonotactics. *Linguistic Inquiry*, 41(4), 623-661

Kaplan, R., and Kay, M. (1994). Regular models of phonological rule systems. *Computational Linguistics 20*, 331-378

Petersson, K. M., Forkstam, C. & Ingvar, M. (2004). Artificial syntactic violations activate Broca's region. *Cognitive Science* 28, 383–407

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, 6, 855–863