Two Case Studies in Phonological Universals: A View from Artificial Grammars

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This article summarizes the results of two experiments that use artificial grammar learning in order to test proposed phonological universals. The first universal involves limits on precedence-modification in phonological representations, drawn from a typology of ludlings (language games). It is found that certain unattested precedence-modifying operations in ludlings are also dispreferred in learning in experimental studies, suggesting that the typological gap reflects a principled and universal aspect of language structure. The second universal involves differences between vowels and consonants, and in particular, the fact that phonological typology finds vowel repetition and harmony to be widespread, while consonants are more likely to dissimilate. An artificial grammar task replicates this bias in the laboratory, suggesting that its presence in natural languages is not due to historical accident but to cognitive constraints on the form of linguistic grammars.

Keywords: artificial grammar learning; consonants vs. vowels; phonological universals; precedence-modifying ludlings

1. Introduction: Phonological Universals and Artificial Grammars

When asked, "So you are a linguist — how many languages do you speak?", a tongue-in-cheek way that I often respond is "No, that's not what the point of generative linguistics is — what matters is how many impossible languages I don't (and could never) speak". A commitment to biologically-based universal preferences for certain types of grammatical structures over others makes clear predictions about what occurs when individuals are confronted with what Moro (2008) calls "impossible languages" — languages that contain structures not derivable from the primitives of Universal Grammar. Among these predictions, one is that individuals attempting to acquire an impossible language through the manner that languages are naturally acquired by children will not fully master an impossible pattern; see Smith & Tsimpli (1995) for a suggestive case study. A second prediction is that, should structures be introduced into a language that are not compatible with aspects of the universal blueprint/template for natural language, they will not remain stable across generations of users; see Kegl *et al.*

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(1999) for discussion of a relevant case study, and, with a different methodology, Kirby *et al.* (2008). One last prediction is that an attempt to learn and use such patterns would not be represented in the same neural circuits that mediate natural languages; see Musso *et al.* (2003) for a revealing experiment of this sort. In short, the study of impossible languages and their acquisition, their non-persistence over generations, and their neural representation can be highly revealing to aspects of biological universals of language and to their feasibility across multiple timescales.

In this article, I will discuss two universals in the organization of phonological systems: The privileged position of edges in intersyllabic processes, and the asymmetric roles of consonants and vowels in intersegmental processes. My goal is to illustrate the study of universals at two different levels of phonological structure in a more general light by looking closely at different types of case studies. Both will be informed by experiments that use the artificial grammar methodology in order to investigate relative ease of learnability and generalizability of unattested grammatical patterns. By creating artificial and controlled examples of these unattested patterns we can observe whether they are unattested because of pure historico-geographic accident or due to more principled reasons, such as Universal Grammar — a set of analytic biases that prefer certain language types over others. Indeed, Ohala (1986), in his 'Consumer's guide to phonological evidence', recommends invented language games as among the best types of evidence for phonological representations and processes. While typological and theoretical research often repeatedly uncovers a number of universals, and this has the business of various schools of linguistics from Greenberg (1963) to the Principles-and-Parameters framework of Chomsky (1981) to the Optimality Theory model of Prince & Smolensky (1993), sometimes it only takes a few skeptics to say that we simply haven't found enough languages to know whether this is a true generalization or not, and that perhaps waiting for us in the Amazon is a language that violates exactly the universal we take to be central to human language structure.

It is my contention that one of the most effective ways of examining whether there is a true analytic and cognitive bias for one type of linguistic structure over another is in teaching it to experimental participants who have neither in their native language, and seeing whether they learn or prefer one to the other. This pursuit is reminiscent of Hauser's (2009: 190) question:

> Do animal forms fill up the space of possible forms or, more generally, does the genome have the potential to create an unbounded range of variation with no gaps? Answers to this question are only beginning to emerge, but they suggest that there are at least three factors that constrain the range of potential forms, creating gaps that have never been, and may never be, filled.

In other words, certain morphological structures in organisms are unattested, not only as a result of "sampling error" due to a paucity of earth-scouring specimen collection, but because of various factors that Hauser identifies as rendering certain organismal forms impossible: Phylogenetic inertia, lack of relevant environmental pressures that result in selection among the biologically given

options, and physical design constraints. In short, Hauser's conclusion is that, due to the interplay of biologically-determined primitives of organismic form, conditions of generational change, and environmental pressures, certain *logically possible* forms that have never arisen may be *bio*logically *impossible*, and thus may never arise (see also Boeckx & Piattelli-Palmarini 2005: 449). In the domain of language, we find analogous factors at work in explaining why certain linguistic structures are never found: Persistence of successful or efficient linguistic structures, absence of contact or relevant noise that would lead to reanalysis/parameter setting, and certain constraints on what language must deliver to the articulatory-perceptual and conceptual-intentional interfaces.

In what follows, I address two case studies in the organization of phonological systems based on typological research that suggest certain structures are impossible, and use the experimental methodology of artificial grammar learning to test whether such impossible languages can be used and acquired as easily as closely-matched but linguistically natural patterns.

2. Universals of Precedence-Modifying Ludlings

Our first example, related to the abstract representations of precedence among syllables within a word, comes from what at first may appear to be an unusual domain of language use. Language games (think of Pig Latin, for example) — or *ludlings*, as they have been called by Laycock (1972) — exist in virtually every culture, usually among adolescents, either for the social function of group membership ('secret handshakes') or in order to encode/hide information from one's parents/rivals. While ludlings fall into many types, including iterative infixation (e.g., English *ubbi-dubbi*, Spanish *Jerigonza*, Portuguese *Língua do Pê*), perhaps the best known type are precedence-modifying ludlings that operate at the level of syllables, of which French *Verlan* (from *à l'envers*) is most famous (Plenat 1995). Syllable-precedence-modifying ludlings exchange the order of syllables in a word and are most commonly employed in disyllabic words; for example, Verlan transforms French *barjot* 'crazy' into → *jobard*.

Bruce Bagemihl, one of the most ardent proponents of ludlings as an object of linguistic study and as a source of information about possible and impossible operations in the phonological component, conducted an extensive typology of attested and non-attested ludlings (Bagemihl 1989). Some of Bagemihl's generalizations are listed below.

(1) i. No ludling reverses the middle two syllables.
(e.g., *bar.go.tu.li* → *bar.tu.go.li*)

ii. No ludling moves the final syllable to the arithmetic middle.
(e.g., *bar.go.tu.li.na* → *bar.go.na.tu.li*)

iii. No ludling permutes every other segment in a word.
(e.g., *bram.poj* → *am.brjop*)

iv. No ludling permutes feet.
(e.g., *bar.go.tu.li* → *tu.li.bar.go*)

v. No ludling permutes sub-segmental features
(e.g., *tom.duk* → *nob.tug*)

Following Bagemihl's insight that "ludlings extend, modify, or exaggerate attested natural language processes" (p. 492), we concur that precedence-modifying ludlings constitute a rich source of information about spontaneous transformations on phonological representations, free of prescriptive influence, and that given the wide variety of ludling processes, it can be quite revealing what one *doesn't* find.

Perhaps one of the more interesting findings about ludlings in the world at large is the fact that, while disyllabic reversals of the Verlan type are extremely common, one encounters a great deal of variation with words of longer syllable-counts. An immediate question that arises is the source of this variation: Is anything possible? We submit that this variation emerges as the consequence of ambiguity as to the way of representing the basic transformation in disyllabic forms. Indeed, there are at least five different attested ways of performing precedence-modification on words longer than two syllables:

(2) Ambiguity of disyllabic inversion leads to variation on longer forms:

a.	*pii.roo.wal* → *roo.wal.pii*	(Move σ1 (first) to end)	*Fula*
b.	*ka.ma.tis* → *tis.ka.ma*	(Move σF (final) to start)	*Tagalog*
c.	*nu.ku.hi.va* → *ku.nu.hi.va*	Transpose(σ1, σ2)	*Marquesan*
d.	*ya.mu.nu.kwe* → *ya.mu.kwe.nu*	Transpose(σF, σF-1)	*Luchazi*
e.	*va.li.si* → *si.li.va*	Invert order of all σ	*Saramaccan*

What is highly interesting about the five patterns in (2) is the fact that *all of them* are compatible with the disyllabic pattern σ1 σ2 → σ2 σ1. That is, σ1 σ2 → σ2 σ1 can indeed be analyzed as movement of σ1 to the end (2a), movement of σF to the beginning (2b), transposition of σ1 and its immediate successor (2c), transposition of σF and the immediately preceding syllable (2d), or total inversion of the order (2e). It is indeed plausible to think that all five patterns in (2) represent *different ways of generalizing* from the *same ambiguous input*. These ways of extending the disyllabic pattern to tri- and tetra-syllabic patterns have the potential to inform us about how learners generalize based on limited input. However, in the case of ludlings, we do not always know the full corpus of input data, nor whether learners are 'explicitly trained' on how to play, and whether they receive negative evidence or corrections.

One of the best ways to investigate 'poverty of the stimulus' type questions — that is, the question of how learners generalize a pattern from limited input to rarer or differing environments for application — is when the researcher has the ability to control *exactly how poor* the stimulus is. To this end, we decided to conduct an experiment in which we taught a ludling to volunteer participants, controlling exactly what kind of data they would be learning from in the training session prior to testing for generalization.

In Nevins & Endress (2007), we conducted an experiment in which participants were presented with an ambiguous rule involving trisyllabic sequences of nonce syllables: 123 → 321 (e.g., *ka.lei.bo* → *bo.lei.ka*). This

transformation is compatible with at least four hypotheses:

(3) i. Invert the order of syllables.
ii. Exchange the first and last syllable.
iii. Exchange the final and antepenultimate syllable.
iv. Exchange every other syllable (i.e. σj with σj+2).

These hypotheses differ in the instances or kinds of positions they explicitly name, for example, first, last, antepenult. In principle, upon hearing 123 → 321, participants might have chosen any of the hypotheses in (3), all of which account the data. Importantly, these four hypotheses all diverge on their predictions for an input string in which there are tetrasyllabic inputs, as shown for the hypotheses in (3) in their respective order:

(4) i. Invert the order of syllables: 1234 → 4321
ii. Exchange the first and last syllable: 1234 → 4231
iii. Exchange the final and antepenultimate syllable: 1234 → 1432
iv. Exchange every other syllable (i.e. σj with σj+2): 1234 → 3412

The hypotheses in (3iii) and (3iv) are unexpected based on the existing typology of ludlings. There are no extant precedence-modifying ludlings that refer to 'penultimate' or 'every other' syllable. There are two ways to interpret this typological lacuna. One is the result of a sampling error, the failure to find such a ludling due to not looking enough or having too small of a sample size in the world's languages. The other is that it represents a principled gap that is the result of an analytic bias (e.g., Universal Grammar), namely, that 'penultimate' or 'every other' syllable are predicates that are disfavored or disallowed in the construction of hypotheses that generalize to strings of different lengths. On the other hand, (3i) and (3ii) are not only attested in surveys of precedence-modifying ludlings, they are built on primitives that recur time and again in linguistic structural descriptions. We turn briefly to a discussion of the importance of the predicates 'first' and 'last' syllable within the more general context of 'edges of sequences'.

Starting with Ebbinghaus (1885/1913), it has been acknowledged that not all positions in sequences behave in the same way: Items close to the sequence's edges (that is, in the first and the last position) seem to be remembered better than items in other positions. This effect, however, seems to have different subcomponents. Learners do not only remember *that* an item occurred in a sequence, but also *where* in the sequence it occurred; that is, they memorize also the *positions* of items. The memory for positions is most impressively illustrated by intrusion errors in memorization experiments (e.g., Conrad 1960). In such mistakes, participants erroneously recall elements from another list than the one currently recalled; these intrusions, however, often respect the positions in which they occurred in their original list. It thus seems that participants memorize an item's abstract sequential position (e.g., Hicks *et al.* 1966, Schulz 1955). This and related research has revealed that also the positions of items (and not only the identity of items themselves) are remembered better in *edges* than in other positions;

accordingly, most recent models of memory for positions in sequences assume, in some form or another, that only edges have absolute positional codes, and that internal positions are encoded relative to the sequences' edges (e.g., Henson 1998, Hitch *et al.* 1996, Ng & Maybery 2002).

Taking these results as the foundation for constraints on linguistic primitives, we suggest that two-argument operations of precedence-modifying ludlings of transposition (indicated below by [x><y] to transpose x and y (Halle 2008)) can only occur with an edge-syllable and with a syllable defined by a function relativized to that edge:

(5) Repertoire of allowed precedence-modifying operations in natural language:
- i. Total inversion
- ii. Transpose operations limited to *x,f(x)*, where *x* can be FIRST, LAST and where *f(x)* can be
  - PRECEDER(x): The element immediately preceding *x* (e.g., 1[2><3])
  - SUCCEEDER(x): The element immediately following *x* (e.g., [1><2]3)
  - COMPLEMENT(x): The entire sequence in the word excluding *x* (e.g., [1><23] or [12><3])
  - POLAR(x): The opposite edge of the word from *x* (e.g., [1>234<5])
  - DOPPEL(x): The corresponding position to *x* in an adjacent word (e.g., [1>234] [<7]89)

Some examples of the uses of transposition operations on these functions from existing ludlings are shown in (5), where these are typed functions that can occur not only over syllables, but also sub-syllabic constituents such as onset, nucleus, and body (onset plus nucleus):

(6)
- a. *dito → doti* — *Tagalog*
  Transpose (first, successor) over Nucleus
- b. *wudit → duwit* — *Javanese*
  Transpose (first, successor) over Onset
- c. *balaynun → nulayban* — *Hanunoo*
  Transpose (first, polar) over Body
- d. *kenkänsä polk*i *→ ponkansa kelki* — *Finnish*
  Transpose (first, doppler) over Body

Given these restrictions on ludlings to transposition operations and to total inversion, one would expect in ludling acquisition that the most important positions are the first and the last one. Transformations where items in these positions are switched may thus be more acceptable than transformations involving reference to absolute or relative position of non-edge syllables. This would explain why transformations (3i) and (3ii) are attested, while (3iii) and (3iv) are not. Moreover, if learners predominantly attend to the first and the last syllable, then even the choice between total reversal (3i) may not be much more acceptable than (3ii). We investigated these predictions empirically.

In the experiment, participants were first informed that they would witness a 'Martian rite'. In this rite, a chief Martian always pronounces a sentence, to which a subordinate Martian has to reply appropriately. Participants were also informed that these two Martians mastered the rite perfectly, and were instructed to try to figure out what the rite was about. Participants were presented with 25 trials, in which one synthesized voice (the chief Martian) pronounced a three syllable sequence and another synthesized voice (the subordinate Martian) replied with the same syllables but in reverse order.

After familiarization, participants were informed that they would witness the rite now with the chief Martian and another subordinate Martian who masters the rite less well. They were instructed to judge on a scale from 1 to 9 whether the new subordinate Martian's response conformed to the rules of the rite. They were instructed to press 1 if they were certain that the Martian's reply was wrong, 9 if they were certain that it was correct, and 5 if they were unsure. Then they completed 20 trials in which the chief Martian uttered a four-syllable sequence, and the new subordinate Martian replied with the same syllables in one of four different orders. In five of the trials, he replied with a 'natural' transformation. In five trials, this transformation was a complete inversion of the chief Martian's sequence; in other five trials only the first and the last syllable were switched, while the middle syllables remained in place (that is, the order was transformed from 1234 to 4231). In the other trials, the subordinate Martian replied with an 'unnatural' transformation. Half of these transformations were of the form '1234 → 1432', and the remaining transformations '1234 → 3412'. All syllables were consonant–vowel (CV) syllables synthesized with the Mbrola speech synthesizer (Dutoit *et al.* 1996).

As shown in Figure 1, the ratings for natural transformations ($M = 6.42$, $SD = 1.02$) were significantly higher than for unnatural ones ($M = 3.72$, $SD = 1.88$), $F(1,11) = 20.43$, $p = 0.0009$. While natural transformations were rated significantly above 5 (the neutral point), $t(11) = 4.83$, $p = 0.0005$, unnatural ones were rated significantly below, $t(11) = 2.37$, $p = 0.0371$.

The ratings (1234 → 4321: $M = 6.72$, $SD = 1.53$; 1234 → 4231: $M = 6.12$, $SD = 1.20$) did not differ significantly between the natural transformations, $F(1,11) = 1.25$, $p = 0.288$, ns; the ratings of the unnatural transformation (1234 → 1432: $M = 3.23$, $SD = 1.71$; 1234 → 3412: $M = 4.20$, $SD = 2.19$), in contrast, differed, $F(1,12) = 7.91$, $p = 0.017$.

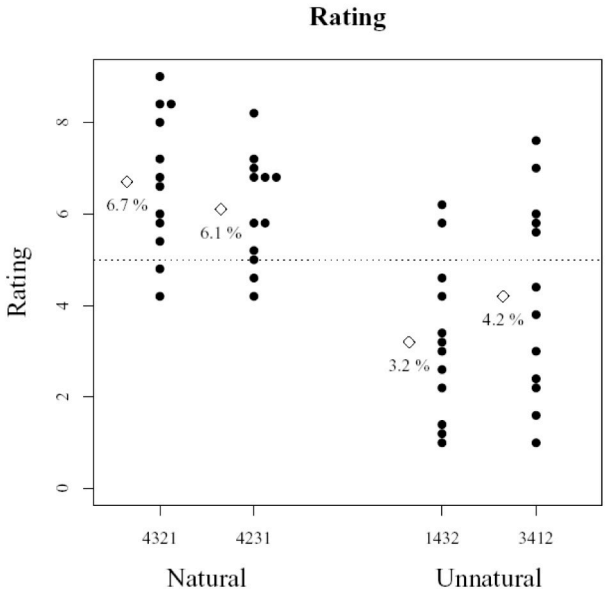

Figure 1: Results of Nevins & Endress (2007; Exp. 1)

These results clearly establish that the 'unnatural' hypotheses in (3iii) and (3iv) were not considered. There may have been a short-circuiting strategy that accounts for the numerical preference for (3iv) over (3iii), in that it is easier to detect that a transformation has not occurred when hearing σ1 in initial position.

The results are consistent with the hypothesis that natural transformations achieved by the operations in (5) are preferred to unnatural ones even though both types are logically 'consistent' with the data. They thus demonstrate an analytic bias in generalization over syllable-precedence transformations, one that exactly lines up with the typology of attested and non-attested extant ludlings.

One possible objection to our interpretation of these results is that they represent some kind of 'general sequence learning' and do not bear on the specific question of primitives of linguistic representation. To examine this possibility directly, we replicated the experiment with musical stimuli.

In a second experiment, the procedure was identical to that describe above, except that tones instead of syllables were used as stimuli. Before familiarization, participants were informed that they would witness a Martian rite, in which the chief Martian played a short melody, and a subordinate Martian had to reply appropriately with another melody. Then participants were familiarized with 30 trials in which the chief Martian played a four-tone melody on an instrument, and the subordinate Martian played its inversion on another instrument. The rationale for using four-tone melodies rather than three-item sequences as in Experiment 1 was that participants usually encode intervals among tones rather than their absolute pitches; in terms of intervals, however, we used again three-item sequences.

After this familiarization, participants were again informed that they would now witness the rite with the chief Martian, and another subordinate Martian who mastered the rules of the rite less well; they were instructed to rate the new Martian's performance on a scale from 1 to 9. The chief Martian (that is,

the same instrument as before) then played a five-tone melody comprising of 4 intervals (corresponding to the four-syllable sequences in Experiment 1). The new subordinate Martian then played a transformed melody in which the interval order (rather than the tone order) was transformed.

Moreover, since intervals are inverted when played backward (e.g., an upward octave becomes a downward octave), the intervals were also inverted. Again, the two natural transformations were 1234 → 4321 and 1234 → 4231, and the two unnatural transformations 1234 → 1432 and 1234 → 3412. Each transformation occurred five times in the test items.

As shown in Figure 2, participants rated the natural transformations (M = 4.89, *SD* = 1.24) better than the unnatural ones (*M* = 4.17, *SD* = 1.18), $F(1,12) = 11.96$, $p = 0.006$. However, participants rated the complete reversal (*M* = 5.46, *SD* = 1.47) better than the transformation 1234 → 4231 (*M* = 4.32, *SD* = 1.56), $F(1,12) = 5.70$, $p = 0.034$ and better than all other three as a group, $F(1,12) = 10.22$, $p = 0.0077$. Moreover, while the complete reversal was rated better than all other transformations (against 1234 → 4231: $t(12) = 2.39$, $p = 0.0343$; against 1234 → 1432: $t(12) = 4.05$, $p = 0.0016$; against 1234 → 3412: $t(12) = 2.33$, $p = 0.0380$), no other pair-wise differences were significant.

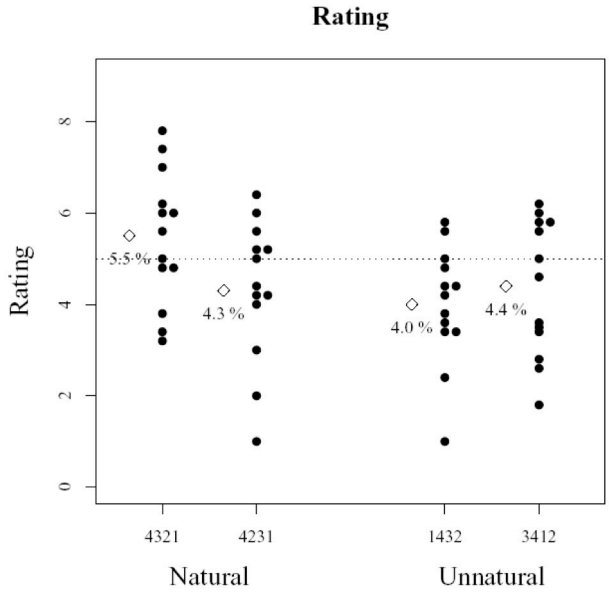

Figure 2: Results of Nevins & Endress (2007; Exp. 2)

When considered in light of the results of the experiment with linguistic stimuli, the results of the second experiment suggest that musical sequence transformations are not learned the same way as linguistic transformations. One possible explanation is that melodies (in particular atonal ones such as the melodies used here) may be encoded predominantly with respect to their *contours* (e.g., Dowling & Fujitani 1971); since all but transformation (3i) change the contour, one may expect that only transformation (3i) should be acceptable. Possibly, one may observe similar results using linguistic material that also features prosodic contours (e.g., suprasegmental tones). However, the question

may also be turned around to ask why edges are special in language but not music. While syllables bear intrinsic properties (such as their segmental content), musical notes largely function solely as links in a contour. While future research may reveal whether the analytic biases for edges in linguistic computation found in our Experiment 1 follow from more basic representational properties of sequence learning, the fact that they did not emerge in our Experiment 2 would suggest that it is words or syllables in particular that implicate a domain-specific learning bias.

Jointly considered, the experiments here allow one to conclude that (i) not every logically possible generalization is actually followed by humans when learning syllable-precedence-modifying ludlings, and (ii) the possibility of edge-switch as the generalization may be unique to linguistic computation. Final & antepenult switch (3iii) and every-other-switch (3iv) cannot be generated using the restrictive primitives in (5), are not found in the typology of existing ludlings, and were not generalized by our participants. The absence of (3iii) and (3iv) in existing ludlings turns out to be a principled rather than accidental gap. The study of universals is thus informed not only by what is shared among the languages of the world, but also by what is missing.

Taken in tandem these two conclusions implicate an analytic bias towards using only certain types of elements in the structural description of syllable-level generalizations — namely left edge, right edge, and ∀ (all syllables in the domain) — which coincides with the typology of existing natural ludlings. Not every way of generalizing a pattern is equally likely, which arguably is a relief for the learner in the face of representationally ambiguous data.

3. Universal Asymmetries between Consonants and Vowels

In this second case study we examine a universal dispreference for consonantal repetition as opposed to vowel repetition, focusing on the typological rarity of vowel dissimilation as opposed to widespread biases against consonantal identity as revealed in statistical analyses and experimental tasks (Berkley 2000, Walter 2007).

The source of this universal asymmetry is related to a more general difference between consonants and vowels. Typological, acquisition, and experimental studies point towards different functional roles for consonants and vowels. Maddieson's (2005) paper in the *World Atlas of Language Structures* reveals that of 564 languages surveyed, all have more consonants than vowels in their inventory. Nazzi *et al.* (2009) find that consonants are more important for vowels in word learning, by showing that when French- and English-learning 30-month old infants must neglect either a consonantal feature or a vocalic feature (e.g., match /pide/ with either /tide/ or /tüde/) that they chose to neglect the vocalic feature. Consonants and vowels are not even learned the same way, as consonants display categorical perception (Eimas *et al.* 1971) while vowels display perceptual magnet effects (Kuhl 1991).

Nespor *et al.* (2003) observe that no language is the inverse of Semitic, having vocalic lexical roots and consonantal glue, Peña *et al.* (2000) find that

consonants are easier for learning word-like 'frames', Surendran & Niyogi (2006) find that consonants have three times the functional load of vowels, and Cutler *et al.* (2000) find that, given a word like *kebra*, experimental participants find it easier to convert the word to *kobra* than to *zebra*. Owren & Cardillo (2006). find that consonants are more important for word identification and vowels are more important for talker identification.

All of these findings point to the conclusion that consonants bear the brunt of building lexical skeleta, and that vowels have a different functional role as grammatical, rhythmic, and sociolinguistic glue. As Nespor *et al.* (2003) point out, distinctiveness between consonants within a word tends to be maximized, whereas distinctiveness between vowels within a word tends to be reduced. Thus, an important asymmetry concerns the types of phonological processes found in each. Among vowels, harmony, a rule creating sub-segmental identity, is very common, while dissimilation is extremely rare (occurring only among low vowels, Suzuki 1998). Within consonants, on the other hand, dissimilation is extremely common, while consonant harmony, while existent (Hansson 2001), is rarely of the iterative type found in vowel harmony.

Much like the study above we can ask the question of whether these typological findings are simply due to sampling error or whether they reflect true universals. In particular we can ask whether consonantal repetition is dispreferred compared to vocalic repetition. In Nevins & Toro (2007), we investigated this question experimentally with 18 Italian subjects, none of whom had rules of obligatory consonant repetition or obligatory vowel repetition in their language. Thus any differences found between these two conditions should reflect true analytic biases.

The first pattern was a consonant repetition language with a rule of adjacent repetitions of consonants in CVCVCV words, where C1=C2. Vowels were always frames of the form CaCuCE or CiCeCo. These words were played to participants in a continuous 10 minute stream, thus of the form: […*mamukEsisekosakakusE*…] (where E represents a lax vowel), with a 25 ms pause between each word. Participants were told that it was a broadcast of an alien language and that they should listen carefully. After 10 minutes of familiarization we tested participants in 16 trials on two forced-choice tests: One was a recognition task to see if participants recalled the vocalic frames. Thus subjects were asked whether *mamukE* or *mumeki* could be a word in the alien language that they heard. Participants thus only had to pay attention to the transitional probabilities among the stimuli in order to successfully discriminate between items that they recognized.

In the generalization test, participants were asked 'which of these could be a word in the language you heard: *Babure* or *ribero',* where both words respected the vocalic frames presented during exposure, but in one of which C1=C2 and in the other C1=C3, which was incongruent with the pattern presented during exposure. According to the distinctness-of-skeleta hypothesis, this rule should be hard to learn. Results of both tests are shown in Figure 3 below, with means indicated by a triangle.

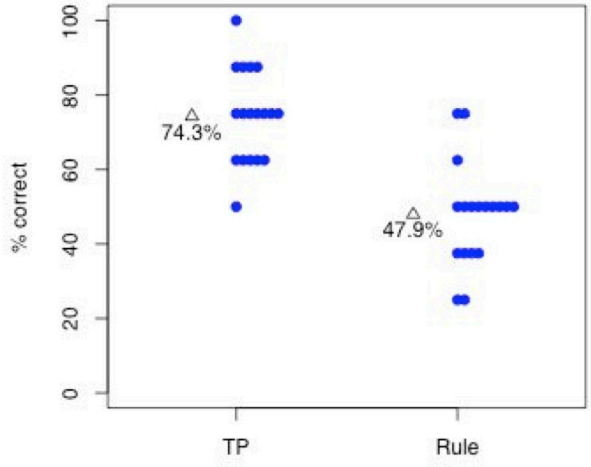

Figure 3: Results of Nevins & Toro (2007; Exp 1)

In the second experiment, we reversed the pattern. Consonants were the transitional-probability glue (mVkVfV or bVsVrV), and rules of adjacent repetition were defined over vowels where V1=V2 [...*mekefubisiromikifemobosa*...]. The procedure was otherwise identical to that of the first experiment. In a recognition task, participants were asked whether *mekefu* or *kefebu* was a possible word, and in the generalization task they were asked whether *makafu* with V1=V2 or *busaru* with V1=V3 was a possible word. Results are presented below, with means indicated by a triangle.

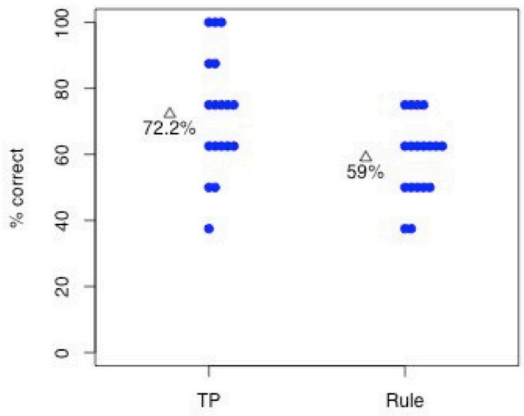

Figure 4: Results of Nevins & Toro (2007; Exp 2)

Recognition tasks did not differ from each other in the two conditions, $t(34) = -.40$, $p = 0.69$. However, the results of the two generalization tasks did, with generalization of the vowel repetition rule (M= 59%, SD = 11.9) much better than generalization of the consonant repetition rule (M=47%, SD = 13.7), $t(34) = 2.59$, $p = 0.014$. In the consonant-repetition condition, participants' discrimination of which of two stimuli 'belonged to the alien language' did not differ from chance, $t(17) = -0.64$, $p = 0.53$. By contrast, in the vowel-repetition condition, participants discrimination of which of two stimuli belonged to the alien language displayed a significant difference from chance, $t(17) = 3.20$, $p = 0.005$. In sum, people can

learn a repetition rule over vowels much better than over consonants.

Again, this experimental methodology with segmental processes of vowel and consonant anti-identity effects points to the same type of conclusion as in the syllabic processes of precedence-modification discussed above: The universal patterns observed through typological sampling of the world's languages can be tested in the laboratory to see if certain gaps are accidental or principled. Across the globe, there is a dispreference for consonantal repetition within words, and this same bias can be observed in failure to generalize during an artificial grammar experiment.

4. Concluding Remarks

The pursuit of universals must involve a three-fold approach: Rigorous typological sampling in order to catalogue what types of patterns are more common than others, formal modeling of the computational primitives that allow or favor one type of pattern over another, and experimental testing of whether the observed typological asymmetries and concomitant analytic biases are upheld in testing situations in which participants have no reason, other than Universal Grammar, to favor one type of pattern over another.

Returning to a parallel with the relation between possible and attested form in the study of organisms, Hauser (2009: 190–191) discusses the relevance of experiments such as those of Abzhanov (2004), based on beak shape in the Galapagos finches. In a certain sense, experimental genetic manipulations of organisms may be seen as analogous to the manipulations occurring in ludlings, insofar as the former are an attempt extend, modify, or exaggerate attested natural growth processes, much as the latter extend, modify, or exaggerate attested natural language processes. In these experiments, the genes encoding the proteins responsible for beak growth in large-beaked finches, bone morphogenetic protein 4 (BMP4), were inserted into a chicken embryo, in order to understand the genetic primitives that lead to possible forms in nature. The result of these experiments is the smoothly unfolding development of chick with a large, broad beak, instead of the small beak that is typical of chickens. Hauser's (2009: 190–191) conclusion is that these studies underscore the importance of experimentation to understand constraints on organism form, as a complementary strategy to typological and naturalistic observation:

> It also shows why cataloguing variation in living animals is insufficient for understanding both the range of variation and its potential constraints; experimental studies such as those with chickens are necessary to uncover the limits of variation.

In this article we have discussed the importance of experimentation with invented ludlings for understanding two levels of phonological structure, intersyllabic processes and intersegmental processes, and attempted to demonstrate that two proposed universals — one derived from the seemingly obscure domain of ludlings and one derived from the well-known dualistic division between consonants and vowels — are both upheld in experimental

scenarios in which historico-cultural diachronic contingencies are rendered irrelevant, and in which the only remaining explanation for the observed linguistic asymmetries remains profoundly cognitive.

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