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Harmonic biases in child learners: In support of language universals

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Abstract

A fundamental question for cognitive science concerns the ways in which languages are shaped by the biases of language learners. Recent research using laboratory language learning paradigms, primarily with adults, has shown that structures or rules that are common in the languages of the world are learned or processed more easily than patterns that are rare or unattested. Here we target *child learners*, investigating a set of biases for word order learning in the noun phrase studied by Culbertson, Smolensky & Legendre (2012) in college-age adults. We provide the first evidence that child learners exhibit a preference for typologically common *harmonic* word order patterns—those which preserve the order of the head with respect to its complements—validating the psychological reality of a principle formalized in many different linguistic theories. We also discuss important differences between child and adult learners in terms of both the strength and content of the biases at play during language learning. In particular, the bias favoring harmonic patterns is markedly stronger in children than adults, and children (unlike adults) acquire adjective ordering more readily than numeral ordering. The results point to the importance of investigating learning biases across development in order to understand how these biases may shape the history and structure of natural languages.

Keywords

learning biases; language acquisition; artificial language learning; typology; universals; word order

1. Introduction

1.1 Learning biases in language acquisition

A number of researchers have hypothesized that languages are constrained or shaped by tendencies, preferences, or biases that are part of the process of learning. While a number of distinct mechanisms have been proposed to link learning and language structure, the core of this hypothesis remains the same. First, certain linguistic patterns systematically recur across languages. Second, this systematicity is in part produced by processes active during

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language acquisition. A range of evidence from various theoretical perspectives has supported this view (Bever, 1970; Newport, 1981; Slobin, 1973; Morgan & Newport, 1981; Morgan, Meier & Newport, 1987, 1989; Newport & Aslin, 2004; Fedzechkina, Jaeger & Newport, 2012; Wilson, 2006; Finley & Badecker, 2008; Berent, Lennertz, Jun, Moreno & Smolensky, 2008; Hudson Kam & Newport, 2005, 2009; Culbertson, Smolensky & Legendre, 2012; among others). For example, Morgan et al., (1987) found that learners are biased to rely on particular cues to phrase structure which tend to be found frequently across languages, and they do not successfully acquire languages that are missing those cues. In a different domain, Berent et al., (2008) showed that learning appears to be guided by a universal hierarchy of sounds organized by sonority. Following on natural language acquisition research by Singleton & Newport (2004), Hudson Kam & Newport (2005, 2009) showed that learners do not replicate patterns of unpredictable variation, suggesting a bias against such variation in grammatical systems. Some of these investigators have suggested that the biases uncovered in learners reflect properties of the language faculty; some have invoked cognitive biases involved in pattern learning or other functional constraints. In any case, their effect is generally argued to promote those language structures which are more readily learnable and reduce or eliminate those which are more difficult to learn or more unlikely to be acquired successfully. Despite these convergent findings, however, the connection between language acquisition and language structure remains heavily debated.

This is in part due to the complexity involved in discerning the underlying cause of so-called typological universals or generalizations, used by some linguists to argue for a set of core universal principles of grammar (e.g., Chomsky, 1988; Baker, 2001; among others). Typological universals describe frequency differences among logically possible patterns across human languages. When a particular pattern (or set of related patterns) is very common compared to alternatives, this represents a potential typological universal. Nevertheless, not every such frequency difference, however intriguing, necessitates an explanation in terms of bias in the linguistic or cognitive systems of individuals. In fact it has been argued that few if *any* reveal meaningful biases (Evans & Levinson, 2009; Dunn et al., 2011), as the frequency of language types reflects the conflation of many non-cognitive factors, including genetic relationships among languages and geographic, socio-cultural influences (de Lacy, 2006; Bybee, 2009; Atkinson, 2011; Dunn et al., 2011). Advances in theories of learning mechanisms also suggest that language acquisition may succeed with a reduced set of language-specific constraints, or possibly with only domain-general learning biases (Saffran, Aslin, & Newport, 1996; Chater & Manning, 2006; Perfors, Tenenbaum & Regier, 2011; Pearl & Sprouse, 2013). These issues, along with the fact that many so-called universals are statistical rather than absolute, call into question the classic view of language variation constrained by universal principles of the linguistic system.

On the other hand, recent work using artificial language learning paradigms has provided behavioral evidence of cognitive biases in line with universals hypothesized based on typology (Newport & Aslin, 2004; Wilson, 2006; Finley & Badecker, 2008; Berent et al., 2008; Hudson Kam & Newport, 2005, 2009; Culbertson et al., 2012; Fedzechkina et al., 2012; among others). Importantly, however, most of these studies have tested *adult* learners, who bring a range of knowledge (both linguistic and otherwise) to laboratory learning tasks.

Thus any biases found in these studies potentially differ—either in content or strength—from those at play during first language acquisition.

In this paper, we report the results of an experiment with young children investigating the learning of word order patterns suggested by Greenberg (1963) as typological universals. We compare previous results from *adult* artificial language learning of word order (Culbertson et al., 2012) to *children's* behavior in a parallel task. We provide the first evidence that, like adults, children show a preference for harmonic or consistent word ordering patterns, in line with one of Greenberg's universals. Our results also reveal that adult and child learners differ in several ways—in particular, the *strength* of their biases, and the apparent role played by a particular lexical category, namely adjectives. These findings strengthen and extend the evidence connecting linguistic typology to learning biases and shed light on how these biases may change through development. While our main focus is on whether a particular set of syntactic language universals arises in a controlled study of language acquisition, we return in our discussion to a consideration of what types of mechanisms could account for our findings. In particular, we outline how the biases we find might be formalized in a more traditional view of linguistic universals and, alternatively, in a view which takes them to result from general cognitive principles.

1.2 Learning biases and word order universals

As mentioned above, a number of studies have found evidence of linguistic and cognitive biases at work during laboratory learning of artificial languages. In some cases, the biases revealed appear to parallel typological asymmetries. For example, a number of studies have found biases relevant to phonological patterns, including vowel and consonant harmony (Pycha, Nowak, Shin & Shosted, 2003; Wilson, 2003; Finley & Badecker, 2008), velar palatalization (Wilson, 2006), and dependency length (Newport & Aslin, 2004; Pacton & Perruchet, 2008). In the domain of morphology, the suffixing preference (Greenberg, 1957) has been tied to cognitive or perceptual biases (e.g., Slobin, 1973; St. Clair, Monaghan & Ramscar, 2009; Hupp, Sloutsky & Culicover, 2009), and the general preference for efficient morphological marking (Greenberg, 1963; Comrie, 1989; Jäger, 2007) has recently been revealed in laboratory learning of case marking by Fedzechkina et al., (2012). Hudson Kam & Newport (2005, 2009), mentioned above, investigated children's acquisition of unpredictable variation (in particular, alternation between two determiner forms which varied inconsistently). Such variation is not common in the world's languages, and results showed that in fact child learners presented with such a system tend to regularize it. Adult learners also regularized under some conditions, but less readily than children. Here we investigate this regularization bias in combination with learning biases connected to typological asymmetries in *word order*—some of the best known of which were uncovered by Joseph Greenberg in his seminal (1963) work.

One such pattern is the well-studied typological preference for consistent or *harmonic* ordering patterns (Greenberg, 1963; Hawkins, 1983; Chomsky, 1988; Dryer, 1992). This has been formalized as the “head directionality” parameter in the Principles & Parameters framework (Baker, 2001). In the nominal domain, for example, a harmonic ordering preference can be seen quite clearly. Across languages, particular nominal modifiers (e.g., adjectives, number words, genitive phrases, relative clauses) may appear before or after the noun they modify. Notably, however, languages of the world tend to order these modifying phrases either all before or all after the noun. Table 1 shows the four logically possible combinations of noun with adjective, and noun with numeral word ordering, and their frequency in the World Atlas of Language Structures (WALS; Dryer, 2008a, 2008b). The patterns which order the noun either first or last with respect to both types of modifiers account for almost 80% of the languages in this sample.

Table 1 illustrates not only the relative frequency of harmonic patterns, but also an additional typological generalization, known as Greenberg's Universal 18. Greenberg (1963) noted that languages tend not to use *pre-nominal* adjectives together with *post-nominal* numerals. In other words, a language which uses phrases like ‘red bird’ will not be likely to use ‘birds two’. However, the opposite pattern—post-nominal adjectives with pre-nominal numerals, or ‘bird red’ and ‘two birds’—is somewhat more well-attested (e.g., in the Romance languages). Both the patterns just described are non-harmonic: the noun precedes one modifier type but follows another. Why these two patterns differ in frequency is not immediately clear; however, along with the apparent preference for harmonic patterns, it may reflect another learning bias.

As we describe in more detail below, Culbertson et al. (2012) found that adults learning miniature artificial languages tend to favor precisely the harmonic word ordering patterns in Table 1 (see also Christiansen, 2000, for a demonstration of this bias outside the nominal domain). They also showed a particular dispreference for the non-harmonic pattern singled out by Universal 18. These biases interacted with a general tendency to regularize variation: Learners exposed to a variable harmonic pattern, with some non-harmonic residue, reduced that residue, producing a *more* harmonic language. Learners exposed to a variable non-harmonic pattern shifted the target pattern toward a harmonic one. In the sections below, we describe this experiment in more detail and report a parallel study with child learners.

1.3 Adult biases for word order in the nominal domain

Culbertson et al. (2012) designed an artificial language learning task to investigate whether adult learners' biases would parallel the two generalizations illustrated in Table 1. The first generalization is that harmonic patterns are more common than non-harmonic patterns. The second generalization is that, among the two non-harmonic patterns, the one which features pre-nominal adjectives but post-nominal numerals is particularly rare. The paradigm used was that first introduced in Hudson Kam & Newport (2005, 2009), in which learners are exposed to a grammatical system with inconsistent or unpredictable variation—that is, variation without any conditioning factor. Culbertson et al. (2012) exposed learners to input which used one of the four patterns in Table 1 above as the main or majority pattern (heard in 70% of input phrases), but had a residue for each modifier type of the opposite pattern (heard in 30% of input phrases). For example, a participant in the harmonic condition N-Adj, N-Num heard pictures described using phrases with that order—i.e., N-Adj or N-Num —70% of the time, and the opposite order—i.e., Adj-N or Num-N—30% of the time. At test, participants saw pictures and were asked to produce phrases describing them. Productions were scored according to whether participants used the majority order. The hypothesis was that only participants exposed to an ordering pattern *conforming* to a bias would regularize, using the majority order more often than it was found in the input.

The results of the study, shown in Figure 1, revealed that learners regularize variable harmonic patterns most, and the particular non-harmonic pattern violating Universal 18 least. Further, non-harmonic input patterns were often shifted by learners toward harmonic ones. In other words, participants in non-harmonic conditions often re-produced the order for one modifier type veridically, but actually overused the *minority pattern* for the other modifier (e.g., in the Adj-N, N-Num condition they might produce 70% Adj-N, 60% *Num-N*, a switch toward harmonic). This was especially pronounced with the typologically rare non-harmonic pattern Adj-N, N-Num, which learners never regularized, but rather always shifted toward a harmonic pattern.

1.4 Motivation and predictions

The findings reported in Culbertson et al. (2012) suggest a set of biases that might appear during language acquisition, influence how languages are learned, and thus come to shape the distribution of patterns cross-linguistically. However if these biases serve as constraints active during the process of language acquisition, it is important to find evidence for them in a population of learners who are clearly within the time of life during which languages are typically acquired (that is, during childhood).

Below we report the results of an artificial language learning experiment modeled after Culbertson et al. (2012) which targets child learners. Our basic hypothesis is that the biases uncovered in adults will be also be found in children; however, we have reason to believe they may differ along several dimensions. First, Hudson Kam & Newport (2009) found that children's tendency to regularize unpredictable variation is stronger than that exhibited by adults; in particular, children regularized quite dramatically under a wide variety of conditions, while adults regularized less and only under particular conditions. Although regularization was found for adult learners in Culbertson et al. (2012), the findings of Hudson Kam & Newport suggest that more extreme regularization behavior may be exhibited by the young learners tested here. If the biases of child learners are *in general* stronger than those of adults, this should be reflected in the strength of the preferences children show for particular word order patterns (e.g., harmonic ones). Any asymmetry between adults and children could reflect a stronger influence of biases on learning during childhood—consistent with the idea that adults' increased level of experience with (a particular) language and/or their increased cognitive capacities may reduce the effect that such biases have on a new language.

2. Children's learning of nominal word order

In this experiment, we expose child learners to a semantically meaningful artificial language comprised of two-word phrases in which a nonce noun is modified by a nonce adjective or number word. The language and procedure are modeled after Culbertson et al. (2012), but the language is simplified and the procedure extended over two days in order to adapt it for younger learners. The critical features of the study remain the same: The language is variable in the sense that word order in the phrases is not deterministic and not predictable based on any conditioning factor (e.g., the particular lexical item(s)). The manipulation compares learning outcomes across the four ordering patterns described above.

2.1 Participants

Participants were 48 native English-speaking children between 6-7 years of age (22 female, mean age = 6;11, range = 6;0-7;11) recruited from local daycare centers and day camps in the Rochester, NY area. Parents of all participants signed a consent form allowing their children to participate, and children who were 7 years-of-age were additionally administered an oral assent form. Twelve additional participants were excluded due to fussiness or failure to complete the two sessions (5), knowledge of a language other than English (4), or experimenter error (3).

2.2 Stimuli

The visual and auditory stimuli were designed to instantiate nominal phrases of the type described above, in which a noun is modified by *either* an adjective *or* a numeral word. Visual stimuli consisted of four novel objects, shown in Table 2.

The nonce labels are shown in IPA for the object nous and modifiers labels in Table 2 and Table 3 respectively. Note that the nonce nouns all ended in [ə], and the nonce modifiers all ended in a consonant. In addition, modifier vocabulary was designed to be somewhat English-like in order to expedite vocabulary learning. Previous studies have found that, with a lexicon of this size, a miniature language takes approximately 3-5 days of learning for children this age (Hudson Kam & Newport, 2005, 2009; Austin & Newport, in prep). By using these pseudo-cognates for a subset of the vocabulary, children were able to readily learn the lexicon within the two sessions.

The auditory stimuli were comprised of nouns and phrases (with a noun and a single modifier) produced using Mac Text-to-Speech (OS 10.6, speaker "Alex", with pitch augmented using Praat; Boersma, 2001). Stimuli were displayed on a Mac (OS 10.6) computer using PsychoPy software (Peirce, 2009).

2.3 Manipulation

Each participant was randomly assigned to one of four conditions corresponding to the four ordering patterns described in Section 1 above. Following the general paradigm introduced in Hudson Kam & Newport (2005, 2009) and developed in Culbertson et al. (2012), each condition featured a majority order used in 75% of the phrases and a minority order used in the remaining 25% of utterances.[1] Table 4 below illustrates the conditions schematically. As an example, the cell in Table 4 labeled with "1" will be referred to here as condition 1. In condition 1, the majority order in adjective phrases is Adj-N, and the majority order in numeral phrases is Num-N. For this condition, the informant therefore described 75% of pictures involving a noun modified by an adjective using the order Adj-N (e.g., "bluth nerka"), and 25% of such pictures using N-Adj order (e.g., "nerka bluth"), and similarly for

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[1]These percentages differ slightly from those in Culbertson et al. (2012) due to the difference in vocabulary size and the balancing this number of words required.

numeral phrases. Critically, the likelihood of a given order was not dependent on the lexical item; thus the variation in order was of the type called inconsistent or unpredictable by Hudson Kam & Newport (2005, 2009). Note that in conditions 1 and 2, the majority ordering pattern is *harmonic*—that is, in the majority of phrases (75%) the noun appears after (condition 1) or before (condition 2) both modifier types. Conditions 3 and 4, on the other hand, are mostly non-harmonic—the noun tends to appear before one modifier type, but tends to appear after the other.

2.4 Procedure

Each participant was trained and tested during two 25-minute sessions that took place on two consecutive days. Sessions occurred in a quiet room with the child seated in front of a laptop computer and the experimenter seated adjacent. The experimenter read a set of introductory instructions to the child explaining that they would be learning part of an 'alien' language with the help of a cartoon informant named Glermi.

2.4.1 Session 1: Noun training—In the first part of the experiment participants were introduced to the nonce objects and their labels in isolation (pictures were in grayscale). This was accomplished through a series of games (24 trials each) that were progressively more challenging. In the first, participants saw a picture of one of the four nonce objects, heard Glermi provide the correct label for it, and were asked to repeat the label. In the second, a matching game was introduced wherein participants saw a picture of one of the objects, heard the correct label for it, and had to locate the same (or matching) object among an array of all four objects. Following this, participants were tested on their comprehension. They saw randomized arrays of the four objects, heard Glermi provide the label for one of them, and had to choose the picture corresponding to the label. Finally, participants saw one of the novel objects and had to *produce* the correct label for it themselves. Feedback was given after each trial throughout this training. Feedback included points in the matching and comprehension trials for choosing the correct picture. During production, if the participant had trouble pronouncing or remembering a particular object label, the experimenter would help.

2.4.2 Session 1: Phrase training—In the second part of the experiment, participants were introduced to two-word phrases in the language, comprised of either a noun and an adjective, or a noun and a numeral. First, 24 exposure trials were given in which participants saw an object with one of the six adjectival or numeral properties (e.g., a furry 'grifta', or two 'nerkas'). Glermi produced a two-word phrase describing the picture (the order of which was dependent on the participants' condition), and the participant was asked to repeat the phrase. Following this, participants were tested on their comprehension. They saw a randomized array of four pictures as in Figure 2, heard Glermi utter a phrase, and had to click on the picture corresponding to the phrase. Finally, participants saw a single picture and were asked to produce a phrase describing it (e.g., a noun+adjective, or noun+numeral combination). This initial production session will be treated here as practice (that is, will be excluded from scoring), since at this point they have heard only 24 exposure trials and (as discussed below) most have not yet mastered the artificial lexicon. Feedback was given on comprehension trials (in the form of points for a correct answer), but not on production trials. In particular, no feedback about the order in which participants produced words was given. However, if the participant had trouble remembering a particular word, the experimenter would help.

2.4.3 Session 2—Session 2 consisted of the same set of tasks; however, the noun training was shortened (18 trials in each part) and the phrase training was lengthened. Exposure, comprehension and production trials were given in alternating blocks: exposure, comprehension, exposure, production, comprehension, production, comprehension, production. In total, participants heard 80 trials of each type. As in session 1, feedback was given on comprehension trials, but not on production trials. In particular, no feedback was given about the order in which participants produced words. However, if the participant had trouble remembering a particular word, the experimenter would help.

2.5 Results

Production trials were coded for vocabulary accuracy and word order. Both measures were scored by two separate coders, blind to the condition of the learner. Inter-coder reliability was approximately 95% for both. We first report the results of vocabulary learning, then turn to analysis of word order learning. In the latter case we focus on trials in which participants were asked to produce phrases in the language—in particular the production blocks in session 2. These blocks occur after participants have heard all three blocks of exposure trials, and (as shown below) after they are relatively comfortable with the artificial lexicon.[2]

2.5.1 Vocabulary learning—Figure 3 shows the average proportion of phrases in which all the vocabulary items were correct—both the noun and the modifier—across conditions. Errors in which a single sound was replaced, added, or deleted (e.g., [grɪftə] → [gɪftə]) were counted as correct. Performance on the artificial language lexicon during the first (practice) production block in session 1 was relatively poor, but increased dramatically by the production blocks in session 2. Across these critical blocks, vocabulary accuracy was generally quite high across conditions.

To assess the effect of block, condition and modifier-type on correct vocabulary use, four mixed-effects logistic regression models were fit to the data.[3] The first (null) model included only an intercept term. This model was compared to a second which included block as a fixed effect. The likelihood assigned to the data by both of these models was compared using a Likelihood Ratio Test (Lehmann, 1986), a method of nested model comparison that takes into account added complexity. The test revealed a significant improvement over the null model of the model including block ($\chi^2 = 391.75$, $p < 0.05$). An additional model including condition revealed no significant improvement ($\chi^2 = 3.23$, $p = 0.36$). A final

[2]In principle the biases of interest here could also be found in comprehension, and thus in our picture-matching task. However, this task was designed to be very easy for our participants;, indeed accuracy was 85% or above for all conditions, with no differences across condition (compared to model with no fixed-effect for condition: $\chi^2 = 3.05$, $p = 0.99$). Moreover, previous work has found that the regularization bias is strongest in production (as opposed to comprehension or judgment tasks; Hudson Kam & Newport 2009; Culbertson et al., 2012).

[3]All models reported here and throughout include random intercepts for participant, noun, and modifier (as is standard in the psycholinguistics literature). Random slopes justified by the design are included in cases where the model converges, with a preference for participant over items slopes (Barr et al., 2013).

model including modifier type again revealed no significant improvement to the fit (χ^2 = 0.001, p = 0.97). In sum, vocabulary learning generally increased across blocks, but was equally good for numerals and adjectives, and was equally good across word order conditions. This suggests that any differences found among word order conditions are not likely to be due to differences in learning the lexicon across children in each condition.

2.5.2 Majority order use in the production of phrases—Turning to word order learning, our main prediction was that regularization—that is, the extent to which learners reduce variation by increasing their use of the majority word order in the input—would differ across conditions. In particular, we predicted that children, like adults in Culbertson et al. (2012), would regularize harmonic patterns more than non-harmonic patterns, and would regularize least, if at all, in condition 4 (the pattern singled out by Universal 18). Figure 4 shows the average proportion of phrases in which the majority input order was used for each condition across the final three critical blocks in session 2. This figure provides no clear evidence that child learners are engaging in regularization—they are not using the majority order more than it was present in the input. Nevertheless, we analyze the extent to which their use of the majority order differed across conditions to determine whether children exhibit biases for particular word order patterns. We then return to regularization in section 2.5.3 below.

The difference across pattern type is striking when majority order *by modifier type* is shown, as in Figure 5. Children predominantly use the majority order for both modifier types when their input is harmonic. However, when the input is non-harmonic, they only match or exceed the input for adjectives; numerals are very seldom used in their input position. To confirm this, mixed-effects logistic regression models were fit to the data. Comparing performance in conditions 1 and 2 (harmonic) to performance in conditions 3 and 4 (non-harmonic) revealed no significant main effect of pattern type (β = 0.73, z = 1.33, p = 0.18) or modifier type (β = 0.53, z = 1.78, p = 0.08). However, a significant interaction between pattern and modifier type (β = −1.10, z = −3.74, p < 0.05) revealed that participants in the non-harmonic conditions used the majority pattern significantly less often than those in the harmonic conditions *with noun+numeral phrases*. Importantly, then, we have uncovered that children indeed prefer harmonic over non-harmonic ordering patterns. This is revealed particularly in their failure to use the input order with numeral phrases, a point that we return to below.

We also compared performance within each of the pattern types. Among the two harmonic conditions (1 and 2), no significant main effects were found (condition: β = 0.27, z = 0.42, p = 0.67; modifier type: β = −0.02, z = –0.15, p = 0.88); however, there was a significant interaction (β = 0.28, z = 2.58, p < 0.05), with participants in condition 2 using the majority pattern in noun+numeral phrases significantly more often than those in condition 1. This shows that there was no preference for the more English-like condition 1—an important confirmation that young learners' knowledge of English is not driving our results—and, if anything, a preference for *post-nominal* modifiers. Given the initial difficulty with this pattern in the practice production trials, a strong preference along these lines post-exposure is particularly impressive.

Among the two non-harmonic conditions, no significant effect of condition was found ($\beta = -0.13$, $z = -0.74$, $p = 0.46$); however there was a significant effect of modifier type ($\beta = -1.06$, $z = -10.03$, $p < 0.05$), again indicating a change in the word order of numeral phrases. A significant interaction of condition and modifier type was also found ($\beta = 0.14$, $z = 2.12$, $p < 0.05$). This finding suggests that, unlike the adult learners in Culbertson et al. (2012), children did not exhibit a particular dispreference for the non-harmonic Adj-N, N-Num over the alternative non-harmonic pattern; in fact they were slightly but significantly more likely to use the pre-nominal adjective ordering in this condition.

To summarize so far, children are not showing evidence of overall regularization of the majority pattern. Rather, their behavior differs dramatically between the harmonic and non-harmonic conditions. As Figure 5 makes clear, in the non-harmonic conditions, children appear to match and even slightly increase ($t(23)=2.05$, $p<0.05$) the proportion of the input order *for adjective phrases*, but they significantly underuse the input order *for numeral phrases* ($t(23)=-4.01$, $p<0.05$). This is not attributable to a preference for English: in condition 3, the numeral majority order is pre-nominal as in English, but children tend not to use this order. Rather, children are shifting away from non-harmonic and toward harmonic orders—with the direction they shift determined by the majority order of the adjective.

2.5.3 Regularization and pattern choice—Our results indicate clearly that some children are using an ordering pattern which does not match the input pattern. In order to further investigate regularization behavior as well as preference for particular pattern types, we follow Hudson Kam & Newport (2005, 2009) in attempting to determine the pattern chosen by each child. Once we determine this, we can then score their behavior relative to this pattern. This type of analysis makes it possible to determine whether, on the individual level, children are reducing the overall amount of variation, even if they are using a pattern that is not the dominant one in the input. Hudson Kam & Newport (2005, 2009) counted the proportion of learners whose preferred pattern was extremely regular—used in every trial, or every trial but one. They then computed the proportion of learners who behaved consistently by this measure. Here, we calculated the preferred pattern of each child by determining which pattern they used the most. For example, if a child used both pre-nominal adjectives *and* pre-nominal numerals more than 50% of the time, the child's preferred pattern was taken to be the harmonic pattern 1 (Adj-N, Num-N), regardless of the input condition the child was in. Only one child out of 48 did not have a preferred pattern by this criterion (a child in condition 4 had exactly 50% Adj-N, N-Adj); this child was removed from subsequent analyses. We first examine *how frequently* children used their preferred pattern, and then turn to *which* patterns learners actually preferred.

To investigate whether children exhibited regularizing behavior—increasing the overall consistency of the language, even if they did not regularize the majority input pattern—we need to examine the frequency with which children used their preferred pattern (independent of which particular pattern it was). Figure 6(A) shows, for harmonic and non-harmonic conditions (collapsed), the extent to which children acquired a pattern that was more consistent than the input. Across conditions, children tended to use their preferred pattern (whatever it was) more than 75% of the time ($t(46) = 6.30$, $p < 0.05$); thus they have indeed acquired a grammar that is more consistent than the input. Interestingly then, while both adults and children regularize in our task and in Culbertson et al. (2012)[4], adults appear to be more strongly influenced by the input. Children, by contrast, tend to choose a pattern (not necessarily the majority pattern in the input) and regularize that. This is in fact similar to what Hudson Kam & Newport (2009) found, although here the pattern regularized is transparently affected by a bias for harmonic orders.

Figure 6(B) shows the number of children who preferred each particular pattern—pattern 1 (Adj-N, Num-N), pattern 2 (N-Adj, N-Num), pattern 3 (N-Adj, Num-N) or pattern 4 (Adj-N, N-Num)—with shading indicating the input conditions represented. This figure reinforces dramatically the three main results reported above. First, many more children had a harmonic preferred pattern than a non-harmonic preferred pattern (40 vs. 7). This confirms the preference for harmonic patterns found above, and illustrates just how strong the preference in fact is. Second, children in condition 3 were more likely to prefer harmonic pattern 2, while children in condition 4 were more likely to prefer harmonic pattern 1. As discussed above, this reflects the clear preference of learners in non-harmonic conditions to shift toward the harmonic pattern which follows the majority *adjective* order in their input. Third, it is possible to see here that several children in harmonic condition 1 actually completely reversed the order in their input, switching to pattern 2. By contrast, no children in condition 2 switched to pattern 1. Together with the better performance on numerals in condition 2 compared to condition 1 reported above, this suggests that learners favor pattern 2, with its consistent post-nominal modifiers. This is in line with the typology—pattern 2 is in fact the most common pattern cross-linguistically, found about *twice as often* as English type harmonic pattern 1 (see Table 1).

3. Discussion

3.1 Summary

The results of this study reveal that young child learners exhibit a strong preference for harmonic ordering patterns in the nominal domain. Our findings thus solidify the parallel between a learning bias—now found clearly in both adults (Culbertson et al., 2012) and young children— and the high frequency of harmonic compared to non-harmonic patterns across the world's languages. Unlike the adults tested in Culbertson et al. (2012), children did not prefer one of the non-harmonic patterns over the other; however, they did distinguish the two harmonic patterns, preferring post-nominal modifiers to some extent. This is somewhat surprising given that these children speak a language—English—which uses pre-nominal modifiers, but it is in line with the typology: the pattern N-Adj, N-Num is about twice as common as Adj-N, Num-N in languages of the world. Interestingly, these young learners also appear to prioritize adjective order. When exposed to a non-harmonic input pattern, children systematically shifted the order of numerals to be the same as that of adjectives. The input pattern Adj-N, N-Num was dramatically shifted toward the harmonic

[4]Adults in Culbertson et al. (2012) regularized the input order in harmonic conditions from 70% to about 80%. Here across all input patterns, children regularized their *preferred* pattern to a level of consistency of about 85%. Note that, like adults, this is sometimes a regularization of 10% greater than the 75% use of the majority input pattern. However, in cases where children are switching from a non-harmonic to a harmonic pattern, this is a switch from 25% to 85% use of that pattern.

pattern Adj-N, Num-N, while the input pattern N-Adj, Num-N was shifted toward the opposite harmonic pattern N-Adj, N-Num.

3.2 A strong harmonic bias in children

The major finding of our study is that children show a very strong bias for harmonic patterns of nominal word order. Children were more likely to use the majority input pattern if it was harmonic, and the likelihood with which they shifted from non-harmonic to harmonic patterns was much higher than that found for adults in Culbertson et al. (2012); in fact *very few* children acquired a pattern which was predominantly non-harmonic (only 7/47 participants did so; the remaining 40 acquired a harmonic pattern). Interestingly, this bias appears to outweigh children's tendency to straightforwardly regularize the input; rather than reducing variation by reproducing the dominant *input* pattern, children shifted the input to conform to their bias favoring harmonic patterns. Only once we determined the pattern each child shifted to could we see that they reduced of the overall amount of variation as well. This shifting occurred to some extent in adults as well; however in general adults were more likely than children to follow and regularize the input pattern. The evidence we have uncovered here of children's strong harmonic ordering bias provides support for the idea that, over generations of learners, such biases have come to shape the distribution of patterns across the world's languages.

This result makes obvious predictions for natural language acquisition: in the face of noisy word order input—i.e., unpredictable or unconditioned variation in ordering possibilities—children's output should be skewed toward a more harmonic pattern. However, if there is no variation and L1 learners solidify their knowledge of nominal word order very early (as suggested for example by Cipriani et al., 1993; Montrul, 2004; Prévost, 2009), then by the time they are producing nominal modifiers there no longer may be evidence of relative difficulty of particular ordering patterns. This suggests that searching for evidence of a harmonic bias during natural language acquisition (of most languages) may require targeting very young learners and using perception or comprehension rather than production studies. However, there are naturally occurring situations that may be promising for investigating a harmonic bias in production. One of these would be acquisition in settings where there is language contact or bi/multilingualism involving languages with different word order patterns, since exposure to multiple languages with different ordering patterns introduces variation which might lead to errors reflecting learners' biases (see Rizzi et al., 2013 for possible evidence of this this German-Romance bilingual children).

While further research is needed to explore where the harmonic bias may appear in natural language acquisition, the results of the current study clearly reveal its potential to shape the course of learning. Indeed, computational models of learning biases suggest that even subtle preferences, which may not be clearly visible in a single cohort of learners, can be magnified as they compound over generations (Kirby, Cornish & Smith, 2008; Reali & Griffiths, 2009).

3.3 Adjectives drive the selection of the harmonic pattern

The harmonic bias was seen most strongly in the learning outcomes of children in the non-harmonic conditions. In the majority of those children, the shift from a particular non-harmonic input to a harmonic output pattern was not random. Children were much more likely to shift toward the harmonic pattern which followed the *adjective order* of their input. Why might this be? Interestingly, when adults were found to have significant difficulty learning a non-harmonic pattern—as in condition 4 of Culbertson et al. (2012) where the majority pattern was the typologically rare Adj-N, N-Num—they too showed a strong tendency to follow the adjective order. Because this entailed a shift from post-nominal to pre-nominal numerals and therefore toward an overall more English-like pattern, Culbertson et al. (2012) suggested that this might be a reflex of participants' native language preference. However, taken together with the child learning outcomes, a different picture emerges: when a learning bias (in this case, a harmonic ordering bias) works against an input pattern, all things equal, learners will be more likely to master the adjective order and generalize it to numerals, rather than the reverse (see Syrett, Musolino & Gelman, 2012; Nicoladis & Rhemtulla, 2006 for independent evidence of the relative ease of adjective compared to numeral syntax in natural language acquisition).[5],[6] Thus, children learning N-Adj, Num-N master N-Adj and generalize to N-Num; children learning Adj-N, N-Num master Adj-N and generalize to Num-N. Adults are able to overcome the harmonic bias to some extent to master N-Adj, Num-N; however, like children, when they are exposed to Adj-N, N-Num they master only Adj-N, and generalize this to Num-N.

3.4 Two views of the harmonic bias

The strong harmonic bias found in this study, together with previous evidence of a harmonic bias in adults, clearly suggest that some mechanism in the cognitive or linguistic system—not a historical or cultural artifact—is responsible for this long-noted typological universal. What is the precise nature of this mechanism? We see at least two possibilities: a specific constraint on grammatical structures, or a result of a more general bias toward consistency during learning.

The first possibility (*a linguistic bias*) hypothesizes that learners know implicitly how languages should be structured and apply these expectations to the process of learning. This possibility most closely follows the generativist hypothesis of a "head-directionality" parameter (Baker, 2001), but we will suggest a somewhat different formulation. The head-directionality parameter was intended to function as a binary switch which a learner would set (as head-first or head-last) based on evidence from the input and immediately extend to all phrase types. A problem for this formulation is the existence of languages with inconsistent head direction. While various workarounds are possible in order to account for

[5]One possible explanation is the relative salience of adjectives compared to numerals. This is anecdotally supported by children's comments to the experimenter during our task. Children quite often stated enthusiastically that they liked the 'blue one' or the 'blue color' but never made such comments about pictures depicting numerals.

[6]Interestingly, lexical variation in nominal word order is much more likely with adjectives compared to numerals (225 languages with variable adjective order, compared to 10 with variable numeral order according to Matthew Dryer p.c.; see also Dryer, 2008a,b). This flexibility may be more readily allowed in adjectival syntax and restricted in numeral syntax if the former is easier to acquire. An anonymous reviewer also suggests that numeral syntax may be underspecified during acquisition due to the use of numerals in counting and mathematics.

these languages, an alternative is to treat this constraint as probabilistic. A formalization of the harmonic bias within two probabilistic grammatical frameworks can be found in Culbertson & Smolensky (2012) and Culbertson, Smolensky & Wilson (2013). In both, the bias functions as prior knowledge which is integrated with the set of input utterances in a way that can lead a learner to shift a non-harmonic language toward a harmonic one. Put another way, the learner will assume a harmonic pattern a priori and will require more evidence in order to acquire a non-harmonic one.

The second possibility (*a cognitive bias*) is that learners more easily acquire linguistic structures (and perhaps other types of patterns) that are more consistent. How might this work? At a general level, it may be the case that consistent patterns across distinct categories allow for broader generalization and thus faster learning. If a language is consistently harmonic, the ordering rule for one modifier can be generalized to another modifier (regardless of type). If the language is consistently non-harmonic, then generalization from one modifier type to another will not be possible, reducing the number of input exemplars relevant to acquiring the word order of each or generating errors (for example, in expectation or production) if generalization is attempted. If the language is variable—as is the case in our experiment—there will be *some* evidence supporting an analysis of the two modifiers as ordered consistently (either consistently before or consistently after the noun). If each consistent instance is better encoded, and thus strengthens a more abstract structural representation for the two types of modifiers that is harmonic, the outcome of learning will be a grammar which is more harmonic than the input. Of course in order to have the right notion of consistency, the learner still must have some representation of the noun as distinct from the set of categories (e.g., Num and Adj) that modify it, and must also have some tendency to consider the categories Num and Adj as similar. Note that, on this view, there are two types of consistency that appear to be at play during learning (one we have called *regularization* and the other we have called *harmony*). Learners favor regularity within an individual rule; they reduce inconsistent or probabilistic variation by learning one of the forms (often the more consistent or frequent one) more readily. A grammar which deterministically uses a single ordering rule for a given modifier is more consistent than one which probabilistically alternates between two ordering rules. Our results on word order harmony suggest that learners also favor higher-level consistency, one which operates across rules for distinct modifier types. A grammar which uses the same rule for numerals and adjectives is more consistent than one which uses a distinct rule for each type.

These two possible conceptualizations of the harmonic bias do not necessarily generate distinct predictions; however, the latter may be more parsimonious if similar biases for pattern consistency are also found in non-linguistic domains. In any case, the result of the bias in our task is clearly stronger in children than adults. Similarly, there is a stronger tendency to regularize in children (Hudson Kam & Newport, 2005; 2009). Together, these findings suggest that learning biases may generally become weaker as cognitive development progresses; either constraints on grammatical structures may gradually exert less influence over learning, or the ability to learn less favored or less frequent patterns may improve with developmental changes in cognitive abilities.

3.5 No apparent preference among non-harmonic patterns

Both typological evidence and the preferences of adults reported in Culbertson et al. (2012) suggest a distinction between the two non-harmonic ordering patterns investigated here (adjective vs. nominal ordering). However, in the present study we found no evidence for a greater disfavoring in children of the pattern ruled out by Greenberg's Universal 18 (pre-nominal adjectives combined post-nominal numerals), which is the rarest combination in languages of the world. There are a number of possible explanations for this. One possibility is that the preference for N-Adj, Num-N over Adj-N, N-Num found in adults could have been the result of language experience which children at this age do not yet have. Culbertson et al. (2012) note that English allows post-nominal adjectives in a restricted set of constructions, but does not allow post-nominal numerals (or does so even more rarely; see also Goldberg, 2013). This could have driven adult's preferences, but may not be known by children at the age tested here. However, Culbertson et al. (2012) argue against this interpretation of their results. The present results— showing that children most strongly prefer a harmonic pattern characteristic of languages of the world (N-Adj, N-Num), but not their native language—supports even more strongly the idea that linguistic experience is not the primary driver of the biases displayed in our experiments.

A more likely explanation for the lack of distinction among non-harmonic patterns is the apparent strength of children's harmonic preference relative to that found in adults. Adult learners were sufficiently able to overcome their harmonic bias to make learning a non-harmonic pattern possible; the fact that they were able to do so more readily when learning N-Adj, Num-N compared to Adj-N, N-Num supported an additional bias parallel to Greenberg's Universal 18. However, the harmonic bias in children was so strong that almost all of them moved their input toward one of the two harmonic patterns; this may have overwhelmed any difference in learnability between the two non-harmonic patterns.

3.6 Conclusion

Typological universals have long been argued by linguists to reflect constraints on the human language system. However, the fact that many, if not most universals are statistical rather than absolute, has been used to argue that they reflect mainly forces external to the cognitive system—for example, genetic relationships among languages, or historical and cultural factors. Even if cognitive biases are implicated, these may be very general in nature, calling into question the traditional view of universal constraints on the language system. With these issues in mind, we investigated here the psychological reality of two universals—most important, a preference for harmonic word order patterns; and, in addition, a dispreference for combining pre-nominal adjectives with post-nominal numerals. These universals are not absolute; many languages have mixed ordering of heads with respect to their complements, and there are attested languages with Adj-N and N-Num order. Recent research using phylogenetic models has argued that these very generalizations are not the result of cognitive factors but of cultural evolutionary processes specific to particular language families (Dunn et al., 2011).

What we uncovered was very strong evidence of a harmonic bias. Importantly, while previous research has found this preference in adults (Culbertson et al., 2012), our findings here represent the first such evidence for young child learners. The harmonic bias exhibited by children was markedly stronger than that of adults, and revealed an intriguing dependency on adjectival order; children overwhelmingly followed the adjective order when shifting from non-harmonic to harmonic. Evidence of a preference for a particular *harmonic* pattern was found in children even where it was not found with adults. Children were more likely to acquire a pattern with modifiers consistently following the noun—the opposite of English—which is by far the most common pattern cross-linguistically. These strong harmonic effects overwhelmed evidence of the second bias of interest. While Culbertson et al. (2012) found that adults disprefer the typologically rare (non-harmonic) pattern combining Adj-N with N-Num, no evidence of this was found in children. Future work will investigate whether this bias might be revealed by more extensive training or less variation in the input.

While we have suggested two possible mechanisms underlying the harmonic bias, one more clearly linguistic in nature and the other cognitive, more generally our results support a connection between language acquisition, language typology, and language change. Biases like this one may combine with others—both cognition-general and specific to language—and may change in strength and content across development, underscoring the range of factors that may together shape the structure of language. Equally important, our results show that artificial language learning experiments—including with young children—can be fruitfully used both to test hypotheses from generative linguistics and to shed light on properties of the human cognitive and linguistic systems. The results of the present experiment suggest that many other language universals may demonstrate psychological reality when investigated in similar ways. Making progress on these issues is particularly important in light of the ongoing debate over language universals, which has polarized the views of researchers from different perspectives in the cognitive sciences. Our results show that relevant empirical evidence can be found in research on language acquisition, and support the idea that probabilistic mechanisms posited in both linguistic and cognitive frameworks can accommodate many of these views.

Acknowledgments

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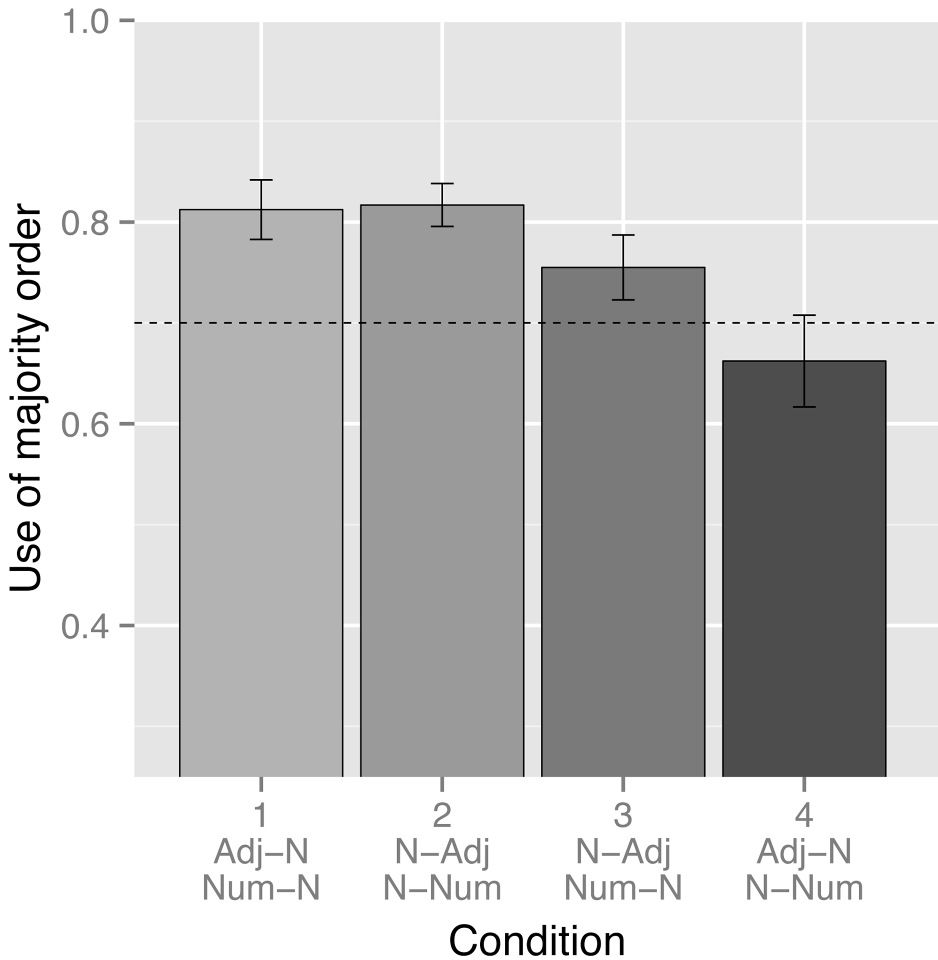

Figure 1.
Average proportion of phrases produced the majority input pattern in each condition as reported in Culbertson et al. (2012). Dotted line represents the proportion of utterances using the majority order *in the input*, i.e. 70%. Light gray bars are harmonic input conditions.

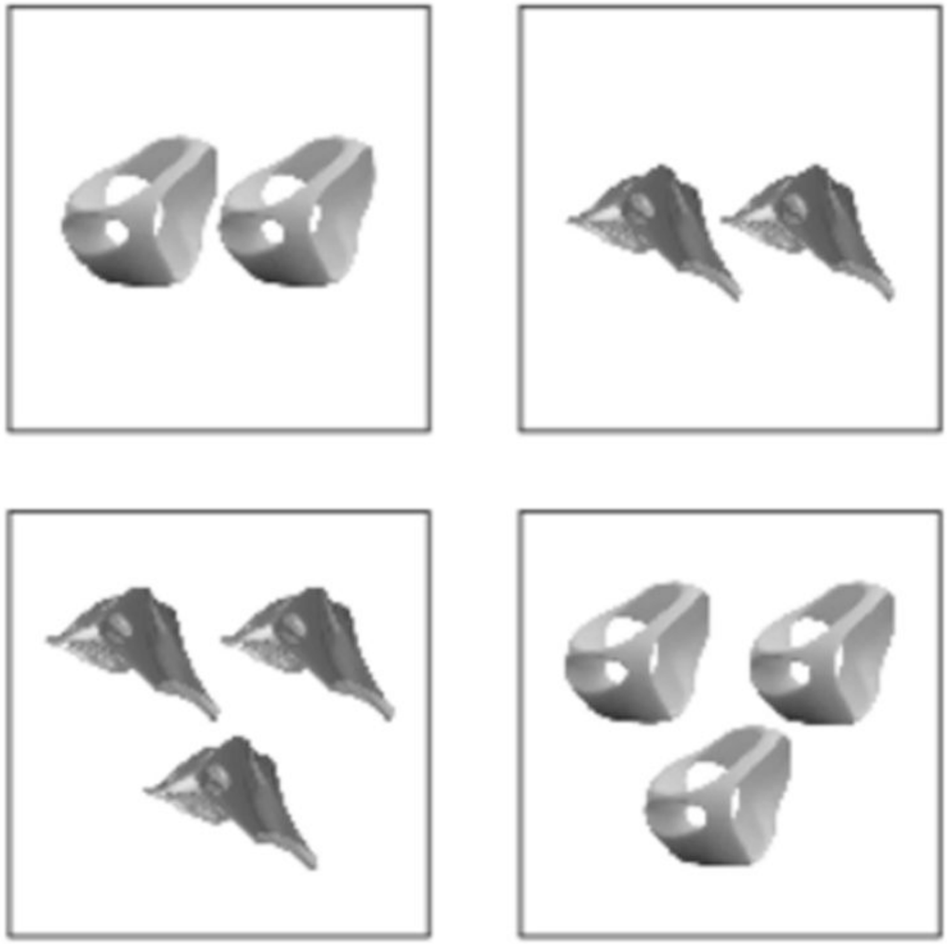

Figure 2.
Example comprehension trial.

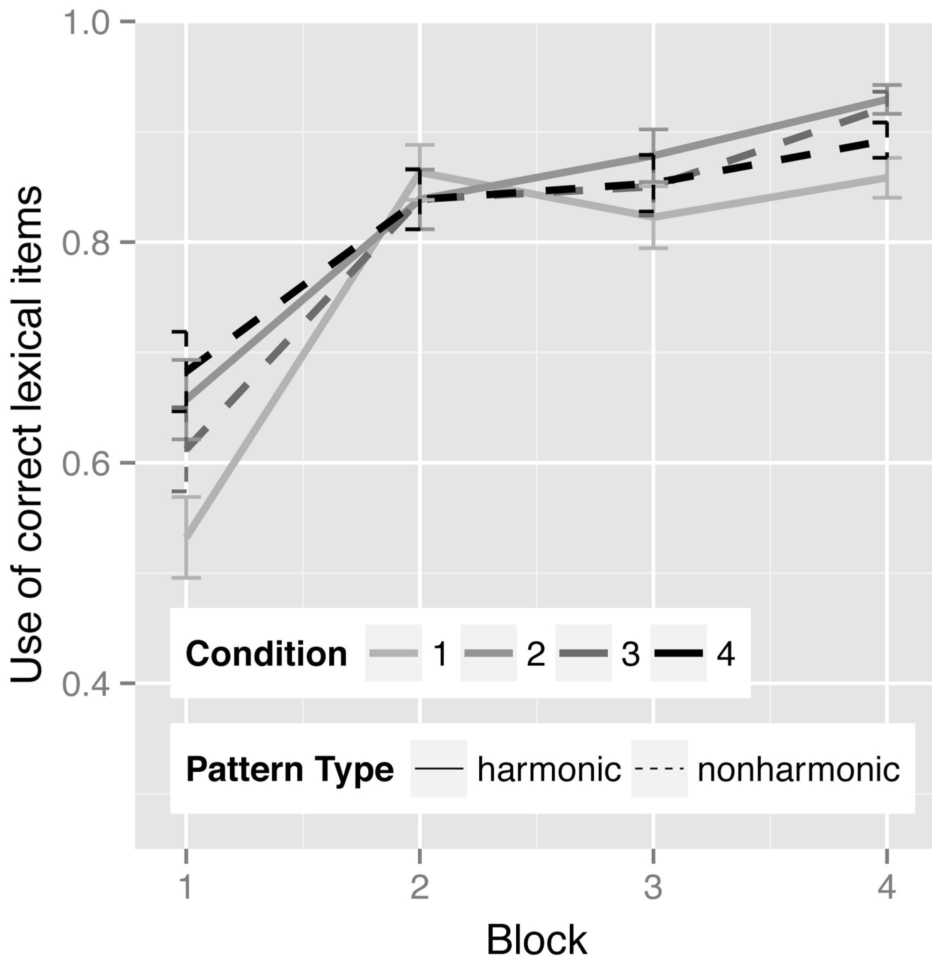

Figure 3.
Average accuracy of lexical items in phrases across conditions. (Here and throughout error bars represent standard error of the mean.)

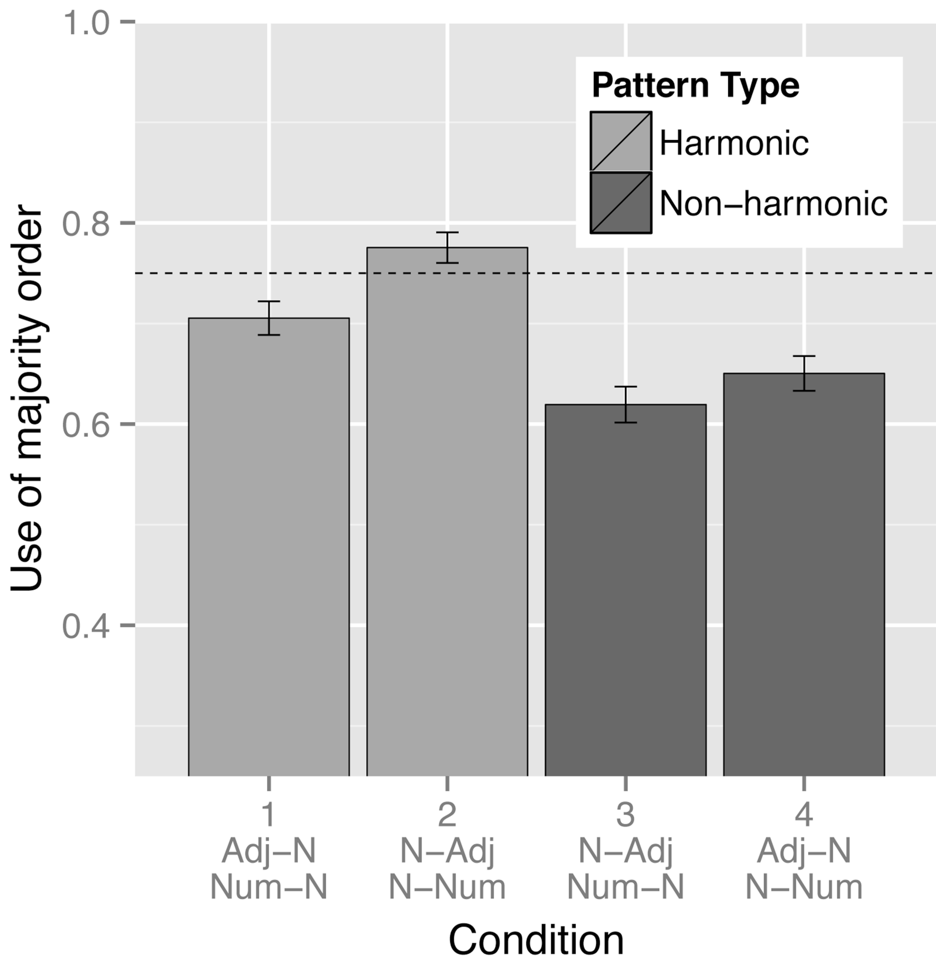

Figure 4.

Average proportion of phrases using the majority input pattern in each condition, with dotted line showing proportion of input utterances using the majority order (75%).

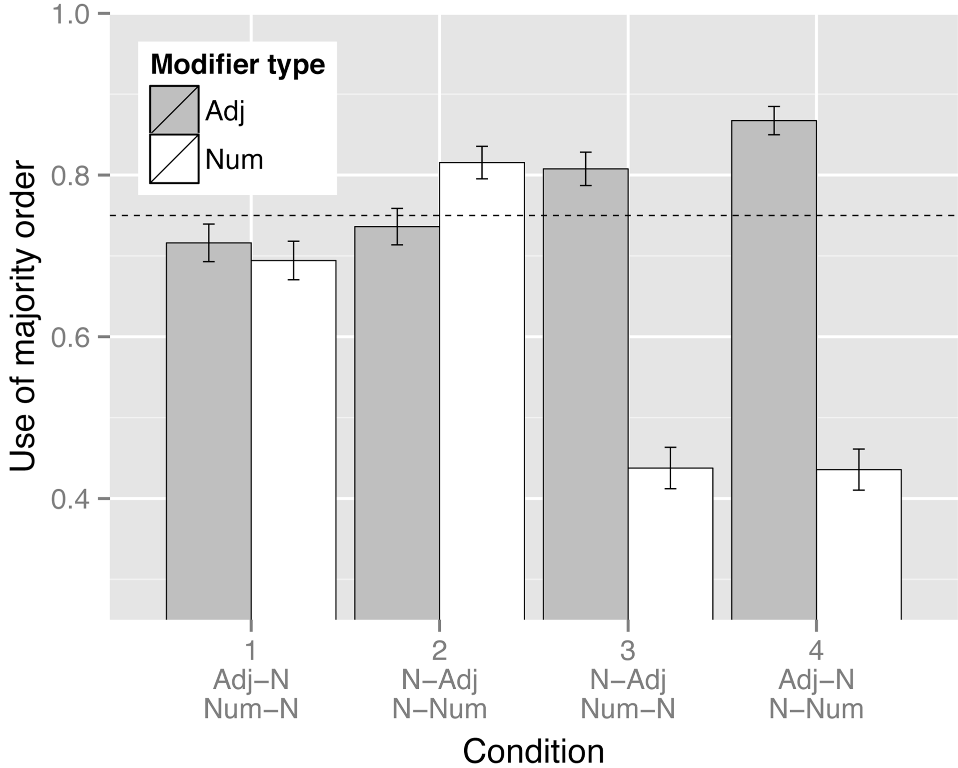

Figure 5.
Average proportion of phrases using the majority input pattern across conditions, broken down by modifier type. Dotted line shows the proportion of input utterances using the majority order (75%).

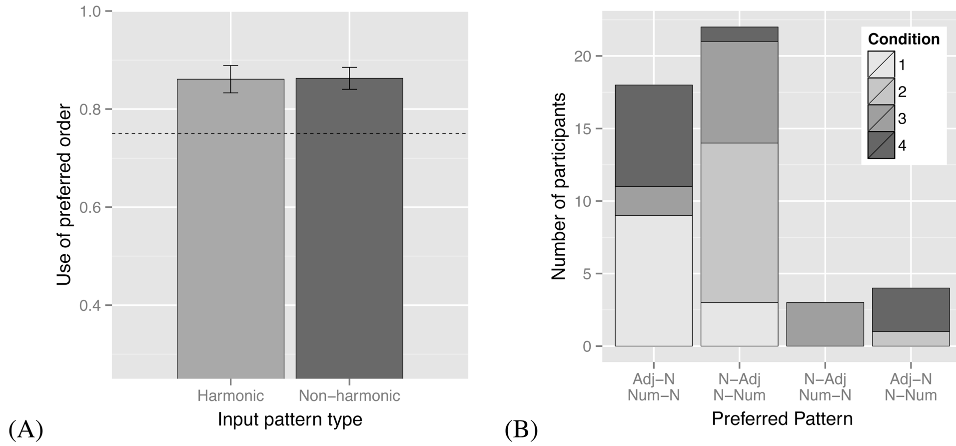

Figure 6.

(A) Frequency with which children used their *preferred pattern* in harmonic and non-harmonic conditions. (B) Number of children whose preferred order exemplified each pattern with gray shades indicating the input conditions. For example, a subset of children from each of the input conditions (indicated as 4 shades of gray) chose pattern 2 as their preferred pattern.

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Table 1

Distribution of languages which (predominantly) use each combination of noun, adjective and noun, numeral ordering in the WALS sample.

	Adjective-Noun	**Noun-Adjective**
Numeral-Noun	227 (27%)	149 (17%)
Noun-Numeral	32 (4%)	443 (52%)

Table 2

Three adjectives corresponding to ‘blue’, ‘spotted’, and ‘furry’ and three numeral configurations corresponding to ‘two’, ‘three’ and ‘four’ (arranged like dots on dice for easy recognition without counting).

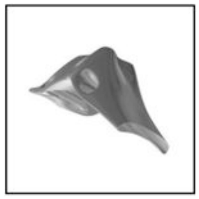
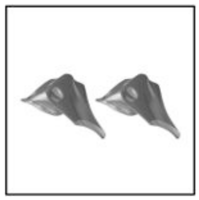
nɛrkə	grɪftə	mawgə	slɛrgə
			
			

Table 3

The nonce adjectives and numerals.

Adjectives		Numerals	
bluθ	'blue'	dof	'two'
sprat	'spotted'	θrɛz	'three'
fləɾf	'furry'	fɔrtʃ	'four'

Table 4

Experimental conditions (each condition featured 75% of the ordering within its cell for a given modifier type—adjective or numeral—and 25% of the opposite order).

	Adj-N	N-Adj
Num-N	1	3
N-Num	4	2

Gray cells are non-harmonic.