Linguistic and Non-Linguistic Influences on Learning Biases for Vowel Harmony

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Abstract

This paper addresses the question of the domain-specificity of learning biases for phonological processes. In two artificial grammar learning experiments we explore the role of learning biases in shaping the distribution of phonological patterns across the world's languages. In Experiment 1, we demonstrate that learners are biased toward phonological patterns that occur in natural language, as opposed to patterns that are not found across the world's languages. Specifically, learners are biased towards directional vowel harmony spreading processes. In Experiment 2, we exposed learners to a non-linguistic analogue to vowel harmony. Learners processed spreading such that learners favored the cross-linguistically valid pattern only when the first item of the series underwent spreading. This set of similarities and differences in learning may provide some insight into the origin of learning biases for spoken languages.

Keywords: artificial grammar learning; phonology.

Introduction

The experiments presented in this paper address the hypothesis that typological restrictions on languages are due to learning biases (Slobin, 1973). Specifically, we address the distribution of vowel harmony across the world's languages. Vowel harmony is a phonological process that induces statistical tendencies for words to share the same vowel quality along a particular phonetic dimension. In Turkish, which displays harmony for both backness and rounding, if the first vowel of the word is front and unround (with some exceptions), all following vowels must be both front and unround as well (Clements & Sezer, 1982). Thus, Turkish vowel harmony may be thought of as a directional spreading process in which the leftmost vowel spreads its feature (round, back) to the right.

Vowel harmony languages exhibit both left-to-right and right-to-left spreading characteristics. The direction of spreading can be decided by the morphology of the language (stems are more likely to spread harmony than affixes (Bakovic, 2000)) as well as the characteristics of the input vowels (spreading [+Round] is more likely than spreading [–Round] (Korn, 1969)). The direction of spreading can also be set such that spreading always occurs from right to left or from left to right. One way in which the direction of spreading is never decided is by the number of changes from the input to the output of the phonological process. For example, consider the disharmonic input /– + +/. There are two possible harmonic outputs: [– – –], which changes the feature value of two of the input vowels, and [+++] which changes only one of the vowels in the input. A left-to-right spreading language chooses [– – –] even though two vowels change. Another possibility is to have no intrinsic direction of spreading, but to choose the harmonic output with the fewest changes from the input (in this case [+++]). This type of spreading is termed 'majority rules' because the direction of spreading is determined by the majority feature value of the input (Bakovic, 2000). One peculiarity is that while languages never use 'majority rules' to determine the direction of spreading, 'majority rules' grammars are extremely easy to produce in generative phonology[1]. Generative linguistics assumes that the non-existence of patterns in natural language implies that they should not be generated by the grammar. However, it is possible that the lack of 'majority rules' grammars is due to an accidental gap. Under this assumption, 'majority rules' patterns are grammatically plausible, but the lack of such languages is an accident of history and language sampling.

One way of distinguishing between a principled restriction on the nature of vowel harmony languages and an accidental gap account is through testing for learning biases. If learners are biased against 'majority rules' languages and biased towards a directional harmony pattern, it suggests that the non-existence of 'majority rules' languages is a valid restriction on grammar. Because it is impossible to test learning biases for unattested languages in a naturalistic setting, as there are no naturalistic settings where a 'majority rules' grammar might be present, the artificial grammar learning paradigm is the best method for addressing this question. In an artificial grammar learning paradigm, it is possible to manipulate naturalness, complexity and statistical regularities in a way that is impossible with naturalistic studies of language learning.

The present experiments test whether learners make use of the 'majority rules' strategy when making grammaticality judgments between harmonic items. We present an experimental paradigm in which learners are exposed to a harmony language that is ambiguous between directionality and 'majority rules'. If learners are biased towards directional patterns and against 'majority rules' patterns,

[1] In 'majority rules' grammars, "ties" (e.g., two round and two unround vowels) are decided by a default strategy (lower-ranked constraint).

they should infer a directional pattern given data ambiguous between 'majority rules' and directionality. By pitting 'majority rules' and directional spreading against each other, it will be possible to determine what kind of pattern learners inferred. One reason testing for biases towards directionality and against 'majority rules' (as opposed to direct learnability) is that unnatural patterns may be learned by a language learner given the proper cues (Anderson, 1981). Further, even if 'majority rules' grammars are learnable, it still could be that learners are simply biased against 'majority rules' given the fact that much of their learning data will be ambiguous between other types of harmony (e.g., directional spreading). The present experiments capitalize on this hypothesis by exposing learners to language data that is ambiguous between 'majority rules' and a directional pattern.

Experiment 1

Participants were exposed either to a left-to-right harmony pattern or a right-to-left harmony pattern in which the majority of the vowels in the input spread. If participants learn a 'majority rules' pattern, they will reverse the direction of spreading when the majority feature reverses, but if participants learn a directional pattern, they will be consistent with the direction of spreading.

Methods

Participants All participants were adult native English speakers with no knowledge of a vowel harmony language. Twenty-four Johns Hopkins undergraduate students participated for extra course credit. Participants were randomly assigned to one of three training conditions: Control, Right-to-Left and Left-to-Right.

Design Because 'majority rules' patterns involves choosing the direction of spreading based on the proportion vowels with a particular feature in the input, it is necessary to provide clear evidence that the vowel harmony process involves a change from input to output. Because inputs to grammatical processes are abstract and not available on the surface, we trained participants on a compounding process where the underlying forms are available as separate lexical entries. Participants were exposed to base forms (the inputs) in addition to their concatenation as a compound (participants in the Control condition were exposed to input forms only). Training consisted of three single syllable forms in isolation, followed by their harmonic concatenations. The harmony rule paired back/round vowels together such that a harmonic trisyllabic item contained all front vowels ([i, e]) or all back vowels ([u, o]). The three individual syllables were disharmonic such that their faithful concatenation would be disharmonic. The concatenated form always followed 'majority rules', in one particular direction. Participants in the critical conditions were trained on either right-to-left harmony (Right-to-Left condition) or left-to-right harmony (Left-to-Right condition). All items were ambiguous between directionality and 'majority rules'. In the Left-to-Right condition [pu], [gu], [de] is concatenated as [pugudo], where the final vowel changes to [+Round] to match the feature values of the first two vowels (e.g., [+] [+] [–] → [+ + +]). In the Right-to-Left condition [pi], [gu], [do] is concatenated as [pugudo] ([–] [+] [+] → [+ + +]). There was a 500ms pause between the trisyllabic forms and the concatenated form. There were 24 alternations of monosyllablic words and their harmonic trisyllabic concatenations. All training items involved a single change from the input to the output.

The compounding procedure is similar to the triad procedure used to study phonological processes in infants (Jusczyk, Smolensky, & Alloco, 2002) in which the infants are given two forms followed by their concatenation. While there is some concern that learners do not infer a phonological process in this paradigm, adapting this paradigm to adults makes it possible to alleviate some of these concerns. First, participants were specifically informed that the trisyllabic item was the 'combined form' of the first three monosyllabic items. Second, the forced-choice task (described below) makes it possible to test for preference for left-to-right versus right-to-left spreading.

Table 1: Training Items for Experiment 1

Left-to-Right		Right-to-Left	
bo du ti	bodutu	be du tu	bodutu
gi te ko	giteke	gu te ke	giteke
mo bo di	mobodu	me bo nu	mobonu
pi ke to	pikete	pu te ne	pitene

All stimuli were recorded in a sound proof booth at 22,000kHz by a male speaker of American English with basic phonetic training (had completed a graduate-level phonetics course). While the speaker had no knowledge of the specifics of the experimental design, he was aware that the items would be used in an artificial language learning task. All stimuli were phonetically transcribed, and presented to the speaker in written format. The speaker was instructed to produce all vowels as clearly and accurately as possible, even in unstressed positions. Stress of the concatenated forms was produced on the initial syllable. All sound editing was done using Praat (Boersma & Weenink, 2005). All stimuli contained the same consonant inventory: [p, b, t, d, k, g, m, n]. The vowel inventory for all conditions consisted of [i, u, e, o]. The training stimuli were counterbalanced to contain all possible combinations of vowel sounds. Consonants were also counterbalanced such all consonants appeared equally often in each position. Concatenated words were produced semi-randomly with the condition that any word too closely resembling an English word was intentionally avoided (the final profile of the stimuli contained consistent numbers of vowel and consonant pairs).

Following training, participants were given a two-alternative forced-choice task. In this task participants were given two pairs of three-syllable items. The first member of each pair was the disharmonic form, and the second member was a harmonic form with either spreading from right-to-left or left-to-right (e.g., [pi] [de] [go] [pudogo] vs. [pi] [de] [go] [pidege]). Participants were asked to choose which pair was the one that best fit the language they were trained on. At test, the critical items are reversed such that spreading the majority feature value requires spreading in the opposite direction. If learners infer a directional pattern, then they will accept multiple items undergoing harmony from the input to the output. If learners infer a 'majority rules' pattern, they will reverse the direction of spreading. Test items included 12 Old Items, 12 New Items and 12 New Direction Items. Old and New items have the majority feature reflect direction of spreading that the participant was trained on, but the New Direction items reflect a reversal of the direction that the participants were trained on. Examples of test items appear in Table 2.

Table 2: Examples of Test Items
('majority rules' Items **bold**, Directional Items underlined)

	Left-to-Right	Right-to-Left
Old	de mi ku **demiki** vs. de mi ku domuku	pu mi te pumuto pu mi te **pimite**
New	nu pu ki **nupuku** nu pu ki nipiki	nu pi ki nupuku nu pi ki **nipiki**
New Direction	pu mi te pumuto pu mi te **pimite**	de mi ku **demiki** de mi ku domuku

Procedure All phases of the experiment were run using Psyscope X (Cohen, MacWhinney, Flatt, & Provost, 1993). All participants were given written and verbal instructions. They were told that they would be listening to a language they had never heard before, and that they would later be asked about the language, but they need not try to memorize any forms they heard. They were told that the language would be presented in terms of three single syllable items followed by their combined form. This was done to ensure that participants inferred that the monosyllabic items were in fact the input to the harmonic concatenation. Participants heard all 24 concatenated forms in a random order, repeated 5 times. No information about vowel harmony was given. No semantics accompanied the sound pairs.

Training was followed by a forced-choice test phase in which participants heard the three mono-syllabic inputs followed by a choice of harmonic concatenations: all round or all unround. If the first concatenation of the syllables belonged to the language, they must push the 'a' key on the keyboard; if the second concatenation of the syllables belonged to the language, they must press the 'l' key on the keyboard. Participants were told to respond as quickly and accurately as possible.

Results

Proportions of 'majority rules' responses were recorded for each participant, shown in Figure 1. If participants learned a 'majority rules' pattern, this proportion should remain high for all test items. However, if participants learned a directional pattern, proportion of 'majority rules' responses should be above chance for Old and New test items, but below chance for New Direction Items.

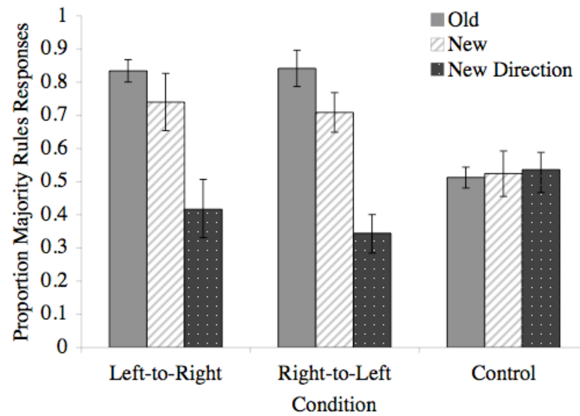

Figure 1: Experiment 1 Results

A 2 (Training) x 3 (Test Condition) mixed-design ANOVA compared each critical condition with the Control condition. There was a significant overall effect of Training for the Left-to-Right condition ($F(1, 14) = 8.90$, $p < 0.05$). There was an effect of Test Item ($F(2, 28) = 5.70$, $p < 0.01$), reflecting greater proportions of 'majority rules' responses in the performance in the Old ($F(1, 14) = 9.67$, $p < 0.01$) and New Test Items ($F(1,14) = 4.95$, $p < 0.05$) compared to the New Direction Test Items. There was a significant interaction ($F(2, 28) = 9.78$, $p < 0.01$), reflecting the fact that there were more 'majority rules' responses for Old Items ($t(14) = 5.29$, $p < 0.001$) but a trend of fewer 'majority rules' responses in for New Direction Items ($t(14) = 2.11$, $p = 0.073$).

There was also a significant overall effect of Training for the Right-to-Left condition ($F(1, 14) = 5.72$; $p < 0.05$). There was an effect of Test Item ($F(2, 28) = 5.04$, $p < 0.05$), reflecting greater proportions of 'majority rules' responses in the performance in the Old ($F(1, 14) = 11.24$, $p < 0.01$) compared to the New Direction Test Items. There was a significant interaction ($F(2, 28) = 7.87$, $p < 0.01$), reflecting the fact that there were more 'majority rules' responses in the Right-to-Left condition for Old Items ($t(14) = 7.43$, $p < 0.001$) but a trend of fewer 'majority rules' responses for New Direction Items ($t(14) = 2.11$, $p = 0.053$).

To test whether participants inferred a directional rule versus a 'majority rules' pattern, we performed contrasts comparing the New Direction test condition to the Old and New items respectively. In the Left-to-Right Condition, there was a significant difference between the New Direction and both the Old ($F(1, 7) = 17.07$, $p < 0.01$) and New ($F(1, 7) = 10.13$, $p < 0.05$) test items. The Right-to-Left condition also showed a significant difference between New Direction and Old items ($F(1, 7) = 17.49$; $p < 0.01$) and a marginally significant difference between the New Items ($F(1, 7) = 5.20$; $p < 0.08$) test conditions. The fact that participants chose the 'majority rules' items significantly less often in the New Direction test condition (compared to Old and New items) suggests that learners inferred a directional pattern rather than a 'majority rules' pattern, reflecting a bias against 'majority rules'[2].

Among the 16 participants in the Experiment 1, only three chose the 'majority rules' item in the New Direction Condition greater than 60% of the time, while three chose the 'majority rules' item 50% of the time, and nine chose the 'majority rules' item less than 50% of the time.

Discussion

The results of Experiment 1 suggest that participants inferred a directional harmony pattern over a 'majority rules' harmony pattern. When learners were exposed to a spreading process that was ambiguous between a 'majority rules' pattern and a directional spreading pattern, learners inferred a directional pattern. This suggests that the non-existence of 'majority rules' spreading processes across the world's languages is in part due to learning biases. Learners do not postulate 'majority rules' languages because they are biased towards directional spreading processes.

However, it is unclear whether this bias is shaped by language-specific constraints or more general cognitive principles, such as attention and memory. Learners may not infer 'majority rules' because such languages require the language user to keep track of the number of vowels of a particular feature value in the input, inducing a greater memory load. Further, there may be a bias in favor of directional patterns, which are in line with attentional biases. For example, in a left-to-right language, it is fully predictable which vowel triggers harmony (the left-most vowel) and which vowels undergo harmony (the right-most vowels). Learners may be biased to infer a directional pattern, given that the consistent cues for harmony are found at the attention-heavy locations in the word (Beckman, 1998). Additionally, 'majority rules' patterns require the learner to keep track of a wider range of conditioning factors: how many vowels of each feature value are in the input, and which direction of spreading to use when there is a tie. A 'majority rules' pattern may require more episodic memory because several different situations in the input induce very different results. For example, two round vowels and one unround vowel will yield round vowels, but three round vowels and four unround vowels will yield unround vowels. While complicated phonological patterns are not uncommon cross-linguistically, if a learner has to decide between a simpler directional pattern and a complicated 'majority rules' pattern, they should choose the directional pattern.

One way to determine whether the directionality preference is due to non-linguistic factors against 'majority rules' is to replicate Experiment 1 with non-linguistic stimuli. If learners of a non-linguistic pattern follow the same constraints on 'majority rules', then it is likely that the bias found in these experiments is due to non-linguistic factors, but if no bias is found in non-linguistic stimuli, it suggests that there is something about the linguistic nature of harmony that biases learners towards directional spreading. Experiment 2 addresses this question with a visual analogue of Experiment 1.

Experiment 2

Experiment 2 addresses whether the bias against a 'majority rules' found in Experiment 1 may be reflected in a non-linguistic version of the vowel harmony learning task.

Methods

Participants All participants were adult native English speakers with no knowledge of a vowel harmony language, and did not participate in Experiment 1. Twenty-seven University of Rochester undergraduates participated for $10. Participants were randomly assigned to one of three training conditions: Control, Right-to-Left and Left-to-Right.

Design The optimal way to test for the effects of non-linguistic constraints on pattern learning is to design a pattern that makes use of known categories, but does not make use of any linguistic strategies. For this reason, a visual learning pattern using colors and shapes is optimal. First, shapes and colors are categories that are readily available to the adult learner, making it possible for the participant to infer a spreading pattern based on the experimenter-defined parameters. Second, the visual stimuli are completely outside the range of linguistic input to the learner, making the pattern learning task as non-linguistic as possible. While non-linguistic auditory stimuli present a closer match to the language learning task, there are two potential problems with such a design. First, standard non-linguistic auditory pattern learning makes use of tones or uncommon sounds that are not clearly defined categories. Thus, it is not clear whether learners of a tone-spreading pattern would make use of the same experimenter-defined categories. The visual stimuli that were chosen for this experiment have definitive categories: shapes (circles and squares) and colors (red, green, blue, yellow). In the present experiment, squares and circles of various colors assimilated based on a spread-right pattern or a spread-left pattern. Second, non-linguistic auditory pattern learning may invoke linguistic strategies to learning (e.g., acoustic properties of the sounds), and therefore may not directly address the questions posed in the present experiment.

It is important to note that the directional labels (left-to-right) are figurative for both Experiments 1 and 2. Left refers to the first item heard/seen; right refers to the final item heard/seen. In the visual analogue, all items appeared sequentially in the center of the monitor for 500ms.

Each input-output pair was presented as a series of three shapes followed by the assimilated version of those three

[2] We also found a significant effect when the alternations were presented as changes from a disharmonic word (as opposed to a concatenation of mono-syllabic words) (Finley & Badecker, 2008).

shapes. Each shape was flashed on the screen for 500ms followed by a 100ms pause in the center of the screen. A 500ms pause was placed between each series of 3 shapes. For example, participants in the Left-to-Right condition, saw /RED SQUARE, BLUE SQUARE, GREEN CIRCLE/ → [RED SQUARE, BLUE SQUARE, GREEN SQUARE]. Participants in the Right-to-Left condition, participants saw /RED CIRCLE, BLUE SQUARE, GREEN SQUARE/ → [RED SQUARE, BLUE SQUARE, GREEN SQUARE].

The training and test items were analogous to the items in Experiment 1. There were 24 training pairs, repeated 5 times each in a random order. There were 12 items each in three test conditions: Old, New and New Direction.

Table 3: Training Items for Experiment 2

Left-to-Right	Right-to-Left
SQUARE SQUARE CIRCLE → SQUARE SQUARE SQUARE	CIRCLE SQUARE SQUARE → SQUARE SQUARE SQUARE
CIRCLE CIRCLE SQUARE → CIRCLE CIRCLE CIRCLE	SQUARE CIRCLE CIRCLE → CIRCLE CIRCLE CIRCLE

Stimuli Shape stimuli were produced using the standard drawing tools for Microsoft Power Point. The shapes consisted of a square and a circle each for four different colors: red, green, blue and yellow, with a small amount of grey shading around each shape. All shapes were standardized to be the same size on the screen (occupying a 5in x 5in space in the center of the monitor).

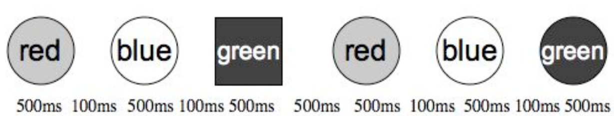

Figure 2: Experiment 2 Stimuli (Left-to-Right)[3]

Procedure The procedure was identical to Experiment 1 except that participants were told that they would be watching a series of shapes, presented as a series of pairs of three shapes.

Results

The proportions of 'majority rules' responses were recorded for each participant, shown in Figure 3. A 2 (Training) x 3 (Test Condition) mixed-design ANOVA compared each critical conditions with the Control condition. There was a significant effect of Training for the Left-to-Right condition (F(1, 14) = 9.83, p < 0.01). There was a significant interaction (F(2,32) = 7.28, p <0.01), due to the fact that there was a significant difference between the Controls for New Items (t(16) = 2.59, p<0.05), but not New Direction items (t(16) < 1). This suggests that learners did not distinguish 'majority rules' and directional items. This is confirmed by a significant effect of Test Item (F(2, 32 = 10.94, p < 0.001), as there was a significant difference between the New Direction items and both the Old and New Items combined (F(1,16)=16.57, *p* < 0.01), suggesting that learners did not infer a 'majority rules' pattern.

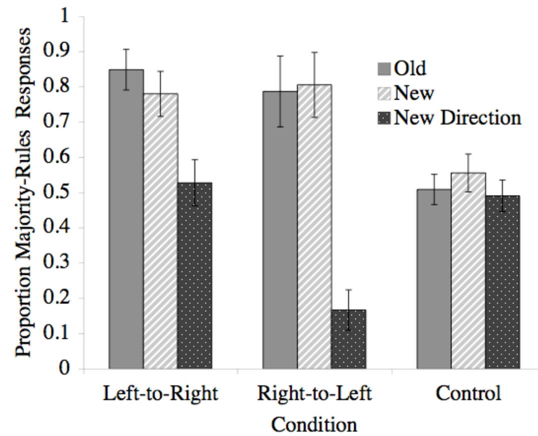

Figure 3: Experiment 2 Results

There was no significant effect of Training for the Right-to-Left condition (F(1, 16) = 1.63, *p* <0.05). This was carried the interaction between condition and test item (F(2,32) = 13.48, *p* <0.001). There were significantly more 'majority rules' responses compared to Controls for Old (t(16) = 2.55, *p* < 0.05) and New (t(16) = 2.33, *p* < 0.05) but there were significantly fewer 'majority rules' responses for New Direction items compared to the Control condition (t(16) = -4.41, *p* < 0.001). This difference reflects the fact that participants in the Right-to-Left condition inferred a directional pattern over a 'majority rules' pattern. The fact that there was no overall significant difference between the Right-to-Left condition and the controls is reflected in the low 'majority rules' responses in the New Direction condition, creating an overall average that was not different from the overall average of the Control condition. There was a significant effect of Test Item (F(2, 32) = 17.66, *p* < 0.001), due to the fact that there was a significant difference between the New Direction items and both the Old and New Items combined (F(1,16)=19.90, *p* < 0.001).

Participants in the Right-to-Left condition learned a directional harmony pattern, while participants in the Left-to-Right condition had no preference. This difference is reflected in the New Direction items, as participants in the Left-to-Right condition chose the majority option significantly more often than participants in the Right-to-Left condition (t(16) = 4.16, *p* < 0.01).

Among the nine participants in the Left-to-Right condition, four participants chose the 'majority rules' item in the New Direction Condition between 40 and 50% of the time, while two chose the 'majority rules' item 25% of the time, and three chose the 'majority rules' item greater than 60% of the time. This variation suggests that there is no intrinsic strategy towards 'majority rules'.

[3] All items were presented in the center of the screen.

Discussion

The difference between the Right-to-Left and Left-to-Right conditions suggests that visual pattern stimuli are processed differently depending on whether the change occurs first in the sequence or last in the sequence. This difference may be due to attentional constraints. If learners pay the most attention to the first part of the sequence, learners in the Left-to-Right condition will notice that there is a change in the first shape, but learners in the Right-to-Left condition will have to wait for the entire three shapes in order to see what changes. Thus, their representation of the pattern may be more holistic, and thus may be more amenable to both 'majority rules' and directional responses. Another possibility is that learners in Experiment 2 were influenced by their prior reading experience, which was left-to-right. This predicts that the opposite pattern should emerge for learners whose reading system is right-to-left. Future research will address these questions.

Because we used namable categories (shapes and colors), it is possible that participants engaged in naming the shape patterns as they appeared on the screen (e.g., 'GREEN SQUARE', 'RED CIRCLE', etc). However, this type of naming is different from the grammatical process that applies in a phonological pattern. First, phonological rule processing is less likely to involve naming (e.g., 'round vowel' or 'u'). Second, if naming the non-linguistic objects induced linguistic processing, we would expect an exact replication of Experiment 1, but this did not occur. In order to replicate a harmony process, it is necessary to use non-linguistic stimuli that have clear categories. Because all stimuli that are a priori categorical have a name, it is not possible to use non-linguistic stimuli that are not namable. Further, participants often create names for non-namable stimuli (e.g., 'the squiggly one') making it unclear if non-namable stimuli would remove naming strategies.

General Discussion and Conclusions

The results of Experiment 1 provided evidence in favor of a learning bias that favors directionality over 'majority rules' patterns. This bias towards directional harmony patterns provides insight into why 'majority rules' patterns do not exist in natural language. If learners are not biased to infer 'majority rules' from their language data, it is unlikely that such a pattern would emerge.

Experiment 2 demonstrated that the attentional constraints that may lead to a bias towards directional spreading pattern must work differently for spoken language versus non-linguistic visual stimuli. In this non-linguistic analogue of Experiment 1, participants only inferred a directional pattern when the spreading pattern occurred from right-to-left, affecting the first image. These results suggest that the source of the learning bias for directional patterns occur as an interaction of the ways in which speakers attend to auditory spoken language. One possibility is that linguistic material is continuous in a way that non-linguistic material is not. This continuity may make listeners more likely to attend to both beginnings and ends of words.

The experiments presented in this paper support the hypothesis that learners have biases that shape the distribution of patterns cross-linguistically. While 'majority rules' spreading patterns may be easily generated by rule and constraint-based theories of phonology, such spreading patterns violate constraints on attention, perception and memory. These constraints bias the learner towards directional spreading patterns over 'majority rules' patterns. In many ways, these biases hold for both linguistic and non-linguistic stimuli, suggesting that domain general constraints may affect the distribution of linguistic patterns across the world's languages.

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