Multimodal Transfer of Repetition Patterns in Artificial Grammar Learning

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Abstract

Extending learned patterns to previously unseen ones is a key hallmark of complex cognition. This paper presents evidence that learners are able to generalize learned patterns to novel stimuli with very different surface properties within and across modalities. Using a statistical learning paradigm, adult learners were exposed to a repetition (reduplication) pattern in which the first element of a three-element sequence repeated (e.g., AB→AAB). The pattern was presented as either spoken repetition (e.g., bago, babago) or a non-linguistic visual analogue (i.e., repetition of non-nameable shapes). Learners showed significant transfer from a non-linguistic repetition pattern to a linguistic reduplication pattern, and vice versa. However, we found a small bias towards linguistic reduplication, as responses to linguistic patterns were numerically higher. This suggests that while learners are able to extend learned patterns to novel patterns in other domains, factors such as familiarity and naturalness may privilege linguistic patterns over non-linguistic analogues.

Keywords: statistical learning, reduplication, domain-general learning mechanisms, generalization.

Domain-generality in Language

One of the most hotly debated topics in the cognitive science of language is whether the mechanisms involved in language acquisition and processing are primarily specific to the domain of language, or whether they may be domain-general and play a role in other aspects of cognition. Domain-specific learning mechanisms have typically been championed by generative linguists, who see language as a highly abstract communicative system governed by complex rules. The complexity and abstractness of these rules have led many to believe that language is one of the key components that separate humans from other species (e.g., Pinker & Jackendoff, 2009). Such language-specific mechanisms provide a possible account for the complexity of language, language universals, as well as the relative ease with which children can learn complicated language systems without explicit instruction.

An alternative account of the complexities of language development focuses on the potential role of domain-general mechanisms in the acquisition and processing of language. This perspective suggests that the regularities found across languages derive from processes of cultural evolution piggy-backing on top of general cognitive mechanisms (Christiansen & Chater, 2008). Constraints on these domain-general mechanisms, amplified by cultural transmission, give rise to recurring cross-linguistic patterns, rather than absolute language universals (Evans & Levinson, 2009). Through cultural evolution, language has been shaped to fit learners, and this helps explain the impressive language acquisition abilities of children (Chater & Christiansen, 2010).

However, empirically uncovering the role of domain-general and domain-specific learning mechanisms in language has proven rather difficult because language development is intertwined with the development of other cognitive functions. A potential way to untangle the contribution of domain-general and domain-specific processes is to explore learning in a controlled environment. Artificial grammar learning paradigms offer a mechanism to explore learning of both linguistic and non-linguistic stimuli in isolation, allowing the researcher to compare domain-general and domain-specific effects of learning in a controlled environment. Under the guise of statistical learning, this experimental paradigm has been used to explore different aspects of learning, such as word segmentation (Saffran, Aslin, & Newport, 1996) and non-linguistic patterns (Kirkham, Slemmer, & Johnson, 2002).

In this paper, we test the hypothesis that domain-general learning mechanisms make it possible to generalize a pattern from a linguistic domain to a non-linguistic analogue, and vice versa. If learners are able to learn novel linguistic patterns in a way that is flexible beyond language-specific learning, they should be able to transfer that pattern to a non-linguistic analogue.

One difficulty in assessing transfer from linguistic phenomena to non-linguistic analogues (and vice versa) is that some linguistic patterns and processes have no straightforward non-linguistic analogue. A non-linguistic version of complex syntactic phenomena, such as non-adjacent dependencies in subject-verb agreement, may be difficult to map onto non-linguistic, domain-general cognition. For example, in English, the subject of a sentence must agree in number with the verb of the sentence, even if the subject and the verb are not adjacent in the sentence (e.g., *The **boys** in the corner **like** bananas*). Such agreement patterns are not easy to translate into alternative domains (though see Onnis, Christiansen, Chater, & Gomez, 2003 for a study of nonadjacency learning using visual nonsense shapes). Even in less 'abstract' domains of language such as phonetics and phonology, it is difficult to find non-linguistic analogues for patterns because phonological patterns would seem to require manipulation of linguistic variables, such as vowels and consonants. For example, German and Dutch have final devoicing, a pattern in which voiced consonants (e.g., /b, d, g/) become voiceless (e.g., /p, t, k/) at the end of a word. Because this pattern is phonetically motivated and manipulates language-specific units, it is difficult to translate this pattern in a non-linguistic analogue.

However, the fact that it is difficult to translate linguistic phenomena in terms of non-linguistic analogues does not mean that such analogues do not exist. For example, reduplication may be an ideal linguistic element to test for cross-modal transfer in artificial grammar learning. Reduplication is a morphological pattern in which an element from a base is copied, thereby creating a repetition of a phonological element (e.g., syllable, segment or entire word). Reduplication is quite common cross-linguistically. Even English has a variant of reduplication in which a word is repeated with *sch* as an onset, in order to de-emphasize a particular word (e.g., ***beer shmeer***, *I'm drinking wine*). While the pattern of reduplication in itself need not relate to semantic content, it in no way detracts from its linguistic function, and the question of domain-specificity in language. The debate of innate and domain-specific language learning capacities includes phonological and phonetic patterns, which do not make reference to semantics.

What makes reduplication ideal for translation into a non-linguistic analogue is its use of repetition. Repetition is a highly salient, common pattern that occurs in a wide range of domains, and can be found in music (e.g., repetition of a note, verse or stanza), in gestures (e.g., waving), in designs (e.g., a wall-paper design in which a set of three flowers is repeated), and in everyday scenes (e.g., a planned community in which every third house is blue, and adjacent houses are red).

Further, repetition has been shown to be a key component in cross-modal transfer in finite-state grammar learning. (Altmann, Dienes, & Goode, 1995; Tunney & Altmann, 2001). Altmann et al. (1995) showed that repetition of items can encourage learners to generalize sequences derived from a finite state grammar across modalities— from spoken syllables to arbitrary symbols, and vice versa. This suggests that learning a reduplication pattern may provide a basis for domain-general generalization, supporting the hypothesis that learners can transfer between linguistic and non-linguistic domains.

Within the statistical learning literature, there have been a multitude of studies investigating linguistic (Frank, Slemmer, Marcus, & Johnson, 2009; Gerken, 2010; 2007; Marcus, Vijayan, Bandi Rao, & Vishton, 1999) and non-linguistic versions of repetition (Fernandes et al., 2009; Frank, et al., 2009; Marcus, et al., 2007; Saffran, Pollak, Seibel, & Shkolnik, 2007). In these studies, infant and adult learners are exposed to patterns of repetition. While there is variation as to which patterns are easiest for infants to learn, there is a general consensus that adult learners are relatively good at learning basic repetition patterns, for both linguistic and non-linguistic stimuli.

While previous studies have shown success in learning linguistic and non-linguistic repetition patterns, these studies have not addressed whether learning in repetition experiments is general enough to support transfer between linguistic and non-linguistic material. The present study builds on previous research in domain transfer in grammar learning, looking specifically at reduplication and repetition. Learners were exposed to a repetition/reduplication pattern for either linguistic or non-linguistic stimuli, and then tested on both linguistic and non-linguistic stimuli. If learners are able to apply the reduplication/repetition pattern to both linguistic and non-linguistic stimuli (despite exposure to only a single modality), it suggests that learners employ domain-general mechanisms in learning novel patterns.

The Experiment

Participants

All participants were adult native speakers of English with no previous participation in any experiment involving reduplication. Forty-eight University of Rochester undergraduate students and affiliates and were paid either $10 or $5 for their participation (participants in the No-Training Control condition were paid $5).

Design

Participants in the critical (trained) conditions were exposed to a reduplication pattern that involved repetition of the first syllable or shape.

Shapes Training Participants in the Shapes Training condition were exposed to 24 sets of non-namable shapes repeated 5 times each. These non-namable shapes were similar in form to those used in Fiser and Aslin (2002). All sets of shapes were of the form AB-AAB, where A and B refer to two different shape items. All shapes were presented in the center of the screen for 500 ms, with a 500 ms pause between AB and AAB, and between each set of shapes. The shapes were presented individually, one at a time. This provided an analogue of linguistic processing, in which sounds are produced serially.

Following exposure, participants were given a two-alternative forced choice task with 48 items. The first 24 items maintained the visual modality. Twelve of the items were found in the training set (Old Items), and the other 12 items were not found in the training set (New Items). The Shapes test items were of the form AAB vs. ABB (with AAB and ABB counterbalanced for order of presentation). Participants were told to select the set of patterns that best represented the patterns they had seen prior to the test. The second 24 test items were presented in the spoken modality, and were the same items given to participants in the Sounds Training condition.

Sounds Training Participants in the Sounds Training condition were exposed to 24 pairs of AB AAB items, in which the first item contained a $CV_1.CV_2$ word, and the second item repeated the first syllable of the first $CV_1.CV_1.CV_2$ word (e.g., [bodu bobodu]).

Following exposure, participants were given a two-alternative forced choice task with 48 items. The first 24 items maintained the spoken modality. Twelve of the items were found in the training set, and the other 12 items were not found in the training set. The test items were of the form AAB vs. ABB, with AAB and ABB counterbalanced for order of presentation, (e.g., [bobode] vs. [bodede]). Participants were told to select the pair of words that best represented the language they had heard prior to the test. The second 24 test items were presented in the visual modality, and were the same items given to participants in the Shapes Training condition.

Materials

Spoken Linguistic Materials Spoken linguistic materials were produced by a native English speaker in a sound-attenuated booth. The speaker had no knowledge of the design or purpose of the experiment. All spoken stimuli contained only CV syllables, with AB stimuli being $CV_1.CV_2$ and AAB and ABB stimuli being of the form $CV_1.CV_1.CV_2$. Consonants were taken from the set: /p, t, k, b, d, g, m, n, f, z, v, z/ and vowels were taken from the set /a, ae, e, i, o, u/. Care was taken so that all of the AB, AAB or ABB forms were non-words in English. Examples of training stimuli can be found in Table 1, below.

Table 1: Sounds Training Items.

AB	AAB
dife	didife
faemi	faefaemi
todi	totodi

Test stimuli were recorded in the same manner as training stimuli. There were 24 test items, 12 containing pairs of words that appeared in training (Old Items), and 12 containing items not heard in training (New Items). Items appearing in the New Items were drawn from the same set of consonant and vowels as the training stimuli. While there were no new consonant and vowel sounds, all syllables in the New Item test items were not in the training set. Examples of test stimuli are provided in Table 2.

Table 2: Sounds Test Items.

Old Items	
AAB	ABB
didife	difefe
faefaemi	faemimi
New Items	
AAB	ABB
dedeza	dezaza
mimibu	mibubu

Shape Materials The shape stimuli were drawn from a set of non-nameable shapes, similar to those in Fiser and Aslin (2002). Non-namable shapes were used in order to ensure that participants did not encode the repetition pattern in terms of the name of the shape, but rather as a purely non-linguistic pattern. The shape stimuli were designed to be as close an analogue to linguistic reduplication as possible. Each shape was analogous to a spoken syllable. Thus, if in the syllable /ba/ were repeated in the AAB sequence, a shape corresponding to /ba/ would be repeated. Because spoken linguistic stimuli are processed sequentially and without reference to space, we presented the non-linguistic shape stimuli in an analogous manner. All shapes were presented in the same location of the computer screen (the center) for 500 ms. Examples of shape stimuli are given in Figure 1. Because it is impossible to show items presented in sequence in the same visual space, time is represented from left-to-right, with times (in ms) below each shape, or pause between shape presentations.

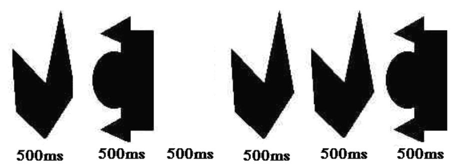

Figure 1: Shapes Training Stimuli.

Test items were created in a similar manner as training items, and followed an analogous procedure to spoken linguistic stimuli items: as AAB vs. ABB (with order of ABB counterbalanced with AAB). There were Old Items that appeared in the training set, as well as New Items that contained shapes that were not in the training set.

Procedure

All phases of the experiment were run in Psyscope X (Cohen, MacWhinney, Flatt, & Provost, 1993). Participants were given both written and verbal instructions, and were debriefed upon completion of the experiment (which took approximately 20 minutes for participants in the trained conditions, and 10 minutes for participants in the Control condition).

Sounds Training Participants in the Sounds Training condition were told that they were to be listening to pairs of words from a language they had never heard before. They were informed that there would be questions about the language following exposure, but that they need not memorize the words they heard. Following exposure, participants were given instructions for the Sounds test items. Participants were told that they would hear two sets of pairs of words. One pair of words was from the language they had just heard, and the other pair of words was not from the language they had heard; if they believed the first pair of words was from the language, they were instructed to press the ‘a’ key; if they believed the second pair of words was from the language, they were instructed to press the ‘l’ key. After responding to the Sounds test items, participants were given the Shape test items. Participants were told that they were to watch two sets of three shapes, and that their job was to select the set of shapes that they preferred.

Shapes Training Participants in the Shapes Training condition were told that they would be watching series of shapes presented in series of five: a set of two shapes followed by a set of three shapes. They were informed that there would be questions about the shapes they saw, but they need not try and memorize the shapes or the sequences that they saw. Following exposure, participants were given instructions for the Shapes test items. Participants were told that they would hear two sets of three shapes. One set of shapes belonged to the series of shapes they had just seen, while the other set of shapes did not belong to the series. If they believed the first set of shapes was from the series they had seen, they were instructed to press the ‘a’ key; if they believed the second set of shapes was from the series, they were instructed to press the ‘l’ key. Following the Shapes test items, participants were given the Sounds test items. Participants were told that they would be hearing two words, and their job was to select the word that they preferred.

No-Training Control Participants in the No-Training Control condition were given test items only (without any exposure to the sound or shape items). All participants received both Sound and Shapes test items, but order of presentation was counterbalanced such that half of the participants were given the Shapes test items first, while the other half were given the Sounds test items first. Participants were told to respond based on their own intuitions about which shapes or sounds they preferred, and that there was no ‘right’ or ‘wrong’ answer.

Results

Proportion of correct responses (i.e., choosing the correctly repeated pattern) for all conditions are given in Figure 1. The means for Old and New items in the Shapes Training condition were identical; 0.70 for both Old and New items. The means for Old and New items in the Sounds Training condition were not significantly different: 0.89 for Old Items and 0.88 for New items (t(15)=0.21, p = 0.84). In order to make a direct comparison between Training and Control conditions, we combined responses to Old and New test items because they were not significantly different from each other. Combining responses for Old and New items allows for a clean comparison with the Control condition, for which all items were ‘new’, as no training was given in this condition.

Sounds Training We compared the Sounds Training (mean = 0.84, $CI \pm 0.075$) condition with the No-Training Control condition (mean = 0.52, $CI \pm 0.09$) via a 2X2 mixed-design ANOVA. There was a significant effect of training ($F(1,30) = 32.08$, $p < 0.0001$, $\eta = 0.52$), suggesting that participants learned the reduplication pattern. There was a significant effect of test item ($F(1,30) = 10.62$, $p < 0.01$, $\eta = 0.26$), which reflected the fact that there were significantly more correct Sounds Test items compared to Shapes Test items. There was no interaction ($F(1,30) = 1.29$ $p = 0.26$, $\eta = 0.041$).

While there were a significantly greater number of correct responses to Sounds items compared to Shapes items in the Sounds Training condition, there was a significantly greater number of correct Shapes responses compared to the Control condition (0.73 vs. 0.49, ± 0.11), ($t(15) = 4.31$, $p < 0.001$). This suggests that participants in the Sounds Training condition successfully transferred the reduplication pattern to the Shapes test items.

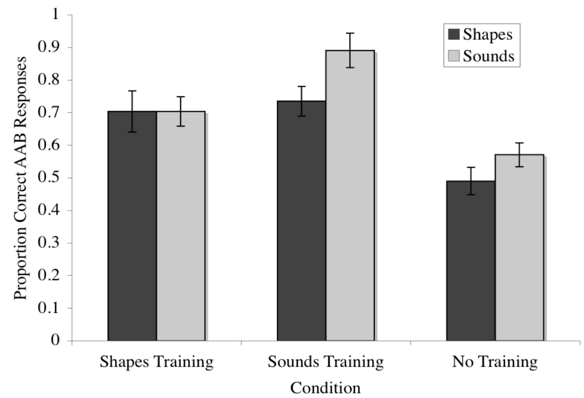

Figure 2: Results.

Shapes Training We compared the Shapes Training (mean = 0.70, $CI \pm 0.084$) condition with the No-Training Control (mean = 0.52, $CI \pm 0.09$) condition via a 2X2 mixed-design ANOVA. There was a significant effect of training ($F(1,30) = 9.85$, $p < 0.01$, $\eta = 0.22$). There was no effect of test item ($F<1$), and no interaction ($F<1$).

There was a significant effect of transfer, as correct responses to Sound items were significantly greater than Sound responses in the Control condition (0.70 vs. 0.57, ± 0.12), ($t(15) = 2.29$. $p < 0.05$).

Overall Because the Control condition was above 50% for Sound items, we compared the performance of the Control participants to chance via a one-sample t-test. The effect was marginally significant ($t(15)=1.95$, $p = 0.070$). This suggests that participants may have had a small bias to prefer reduplication of the first element compared to reduplication of the second element. However, given that all participants were significantly more accurate than controls, this small bias did not affect the overall results.

Participants in both conditions were able to transfer the knowledge learned in one domain to another. Participants trained on a linguistic AAB reduplication pattern transferred that knowledge to a non-linguistic repetition pattern, and vice versa. One interesting pattern of results is that sounds appear to be privileged over shapes. Participants in the Sounds Training condition chose the correct reduplicated item for Sound test items more often compared to responses to Shapes test items in the Shapes Training condition. While there appears to be a transfer deficit for sounds to shapes but not from shapes to sounds, it is unclear whether this is a type of 'ceiling' effect. Learners in the Shapes Training condition showed about the same proportion of correct responses to shape items, even after training, compared to responses to Shape Items in the Sounds Training condition. Third, there was a slight bias towards AAB sound reduplication in the No-Training Control condition, but no biases in the Shapes test items. There are two possible reasons for the greater number of 'correct' responses to sound items. The first is that sound items are in a familiar domain— speech— while the shape items were unfamiliar to participants. This lack of familiarity could have made learning and transfer more difficult. Given that participants had over 18 years of experience processing English sounds, but only a few minutes processing the novel shapes, it is likely that this difference may have produced a difference in responses.

Another possibility is that processing linguistic patterns, such as reduplication are privileged. If this is the case, then it may be easier to learn reduplication in a linguistic domain than in a non-linguistic domain. Marcus et al. (2007) support this notion, as they argue that abstract rule learning in language is privileged. Infants in Marcus et al.'s study were best able to learn the repetition pattern when presented as linguistic stimuli, but failed to learn the non-linguistic pattern. However, infant learners are able to learn the non-linguistic repetition patterns with highly salient input (Frank, et al., 2009) or familiar objects (such as dogs) (Saffran, et al., 2007). The reasons for the privileged status of language in pattern learning may be due to experience, amount of exposure and salience, rather than something inherently special about the linguistic material. However, this question cannot be addressed under the current experiment, and will be left as an open question for future research.

Discussion

We have shown that learners are able to transfer knowledge from a linguistic domain to a non-linguistic domain and vice versa. Participants exposed to a linguistic reduplication pattern were able to transfer that reduplication pattern to a non-linguistic repetition pattern, and learners of a non-linguistic repetition pattern significantly transferred this knowledge to a linguistic reduplication pattern.

The results of the present study have important consequences for theories of language learning and representation. Because many patterns and processes in language do not appear to have clear non-linguistic analogues, it has been largely assumed that linguistic processes are represented independently of non-linguistic processes. Using a repetition pattern that has clear analogues in both linguistic (reduplication) and non-linguistic (repetition) patterns, we have shown that adult learners can move with relative ease between domains (linguistic and non-linguistic) and modalities (shapes and sounds).

Domain-specific theories of language learning predict that non-linguistic patterns are learned via separate mechanisms than linguistic patterns. In such domain-specific learning, representations for linguistic patterns should be highly complex, and represented solely in terms of linguistic units (e.g., consonants, vowels and syllables), and will therefore have no non-linguistic analogue. For example, a domain-specific theory of reduplication might state a rule in which the first syllable of a root is copied to the beginning of the reduplicated word. Because shapes have no syllables or roots, there is no way to represent repetition of non-linguistic items such as shapes or tones. In order to explain the effect of transfer from linguistic to non-linguistic modality in the present study, the mechanisms for learning and representation must be flexible enough so that reduplication can be encoded as repetition.

A question for future research is whether the flexibility of representations in adult learners is specific only to repetition patterns. If all aspects of language are learned via domain-general learning mechanisms, then transfer across modalities should be found for patterns that do not involve repetition. While Altmann et al. (1995) showed that repetition is important in generalization across domains, Tunney and Altmann (2001) showed that transfer across domains does not require repetition if the distributional information in the stimuli is manipulated to induce the relevant analogies.

Another unresolved question pertains to the nature of the representations that support the generalization across domains observed in our study. It may seem that the transfer results would point to some sort of abstract, amodal representation that can be applied across both auditory and visual domains. However, this interpretation is inconsistent with the results of Conway & Christiansen (2006), who found no interference (i.e., negative transfer) between visual and auditory artificial grammar learning. A plausible hypothesis, then, following Redington & Chater's (1996) reevaluation of transfer effects, is that generalization may happen at test given the salience of modality-specific representations of the repetition patterns.

A future study is planned looking at transfer in deletion, which is less salient and (crucially) veers away from repetition patterns. In addition, future research will create non-linguistic analogues of patterns in language that make use of more complex, hierarchical and abstract representations, such as those involving non-adjacent dependencies (e.g., Onnis et al., 2003).

Additionally, future research will determine whether linguistic and non-linguistic patterns are learned via the same mechanisms. Previous research has suggested both non-linguistic and linguistic pattern learning follow relatively similar constraints (Finley & Badecker, 2010; Kirkham, et al., 2002). For example, Finley and Badecker

(2010) compared learners' inferences about linguistic and non-linguistic agreement (harmony) patterns. Harmony is a phonological pattern in which vowels (and consonants) share the same phonetic feature values. Learners of a non-linguistic visual analogue of harmony made similar inferences compared to learners of the phonological harmony pattern. The linguistic and non-linguistic patterns mainly differed with respect to differences in processing visual versus spoken auditory stimuli. Future work will continue to explore the ways in which non-linguistic pattern learning mirrors (or fails to mirror) complex language learning. Only through comparison of multiple learning situations will it be possible to uncover the domain-general and domain-specific interactions that lead to language.

In summary, the present paper explores the role of domain-general learning mechanisms in adult pattern learning. Testing adult learners for transfer from spoken linguistic to visual non-linguistic stimuli, we showed that learners are highly flexible in their interpretations of novel patterns. Participants were able to learn both linguistic and non-linguistic repetition patterns, and were able to transfer that pattern to a novel domain. These results suggest a significant role of flexible, domain-general mechanisms in language learning.

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