Published in final edited form as:

Cognition. 2009 June ; 111(3): 378–382. doi:10.1016/j.cognition.2009.02.010.

From Domain-Generality to Domain-Sensitivity: 4-Month-Olds Learn an Abstract Repetition Rule in Music That 7-Month-Olds Do Not

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Abstract

Learning must be constrained for it to lead to productive generalizations. Although biology is undoubtedly an important source of constraints, prior experience may be another, leading learners to represent input in ways that are more conducive to some generalizations than others, and/or to up- and downweight features when entertaining generalizations. In two experiments, 4-month-old and 7-month-old infants were familiarized with sequences of musical chords or tones adhering either to an AAB pattern or an ABA pattern. In both cases, the 4-month-olds learned the generalization, but the 7-month-olds did not. The success of the 4-month-olds appears to contradict an account that this type of pattern learning is the provenance of a language-specific rule-learning module. It is not yet clear what drives the age-related change, but plausible candidates include differential experience with language and music, as well as interactions between general cognitive development and stimulus complexity.

Keywords

language learning; infant cognition; artificial grammar learning; statistical learning; rule-learning; modularity; music cognition

Much of adult cognition has been characterized as a set of special-purpose processing routines or modules (Marr, 1982; Fodor, 1983; Pinker, 1997), with functions such as face-recognition (Kanwisher, McDermott and Chun, 2002), speech-perception (Liberman and Mattingly, 1985), syntax (Chomsky, 1995), and theory of mind (Scholl and Leslie, 1999). Do these domain-specific capacities characterize the initial state of humans? Are the constraints required for learning specific to particular domains, or is the initial state better characterized by at least some domain-general learning mechanisms that may come to 'fit' themselves differently to different input (Karmiloff-Smith, 1992; Jacobs, 1997; 1999)?

One way in which learning may change during development is by tuning to the properties of the environment. Several examples of such input-based tuning exist in music and language. While younger infants discriminate a broad range of speech contrasts, older infants distinguish mainly those found in their input (e.g., Werker & Tees, 1984; Bosch and Sebastian-Galles,

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2003). The change appears to be driven by the phonetic distributions in the input (Maye, Werker, & Gerken, 2002). Similarly, Gerken and Bollt (2008) showed that, while 7.5-month-olds learn both a “natural” stress rule (one found in human languages) and an “unnatural” rule (one not typical of human language) equally well, 9-month-olds learn only the natural rule.

In music, learners’ perception seems to tune to general properties such as the importance of relative pitch over absolute pitch (Saffran and Griepentrog, 2001; Saffran, 2003), and the importance of tonality and key (Trainor and Trehub, 1992). Learners also become sensitive to the characteristics of music in their own culture, assimilating rhythmic alterations differently depending on the meters of their native music (Hannon and Trehub, 2005), and becoming sensitive to particular scale structures used in their culture by a year of age (Lynch and Eilers, 1992). There is even evidence of infants tuning to species-relevant stimuli in the domain of face recognition (Pascalis, de Haan and Nelson, 2002). Thus, the infant may start as something of a generalist, becoming a specialist through exposure to her environment.

What about specialization across domains? Marcus, Fernandes and Johnson (2007) found that 7-month-old infants fail to learn an abstract generalization (sequences must follow an AAB or ABB repetition pattern) over sequences of tones, though they learn the analogous generalization over syllable sequences (Marcus, et al., 1999). This finding could be taken to reflect a “rule-learning” module that is innately predisposed to process speech sounds. However, a number of recent studies have cast doubt on this claim. Seven-month-olds have been shown to learn AAB/ABB generalizations with pictures of dogs (Saffran, Pollack, Seibel and Shkolnik, 2007), and 11-month-olds with simple shapes (Johnson, Fernandes, Frank, Kirkham, Marcus, Rabagliatti and Slemmer, in press). Furthermore, Murphy, Mondragon and Murphy (2008) found that rats can learn the generalization in both speech and tones. Why, then, do infants fail with tone stimuli?

One possibility is that repetition patterns are available to a domain-general learning mechanism (see Gervain, Macagno, Cogoi, Peña and Mehler, 2008, for evidence that some repetition patterns are learnable by newborns), but that 7-month-olds attend to and/or represent music in a way that prevents them from encoding the abstract generalizations in this case. Whatever the specific encoding factors might be, if the failure is due to attentional/representational changes rather than to an innate domain-specificity of rule-learning, then younger infants might be expected to succeed. We explore this general hypothesis in two experiments. Exp. 1 employed a design similar to that used by Marcus et al. (2007), but with the addition of a group of younger infants who might have fewer attentional/representational biases. Exp. 2 replicated the results from Exp. 1 using slightly different materials.

Experiment 1

Methods

Participants—Eighteen infants (7 females) between 3.5 and 4.5 months (mean 17 weeks) and eighteen infants (7 females) between 7 and 8 months (mean 32 weeks) were recruited from the Tucson area. Data from five additional 4-month-olds and three additional 7.5-month-olds was collected, but was excluded due to these infants’ failure to complete six test trials (3 per grammar) with looking times of at least 2 seconds (the time required to hear one complete phrase). All infants were at least 37 weeks to term and 5 lbs 8 oz at birth, and had no history of speech or language problems in biological parents or full siblings.

Materials—Three-note triads were built on each of the twelve pitches between middle C and the B above. Eight (four major and four minor) were assigned to the familiarization phase, the rest to the test phase. The chord sets for each phase were further divided in half, into an A group and a B group.

Three-chord phrases were created for both AAB and ABA grammars. In both, the two “A” chords were identical. Every combination of A and B elements was represented, for a total of sixteen unique familiarization phrases and four unique test phrases. The B element was higher-pitched half the time in both phases. Each phrase was 2500 ms – 625 ms for each chord with 625 ms of silence at the end.

A two-minute familiarization sequence for each grammar was constructed. Each sequence contained each of the sixteen unique phrase three times, randomized within blocks. The three blocks had different random orders, but the same orders were used for the AAB trial and the ABA trial – i.e., if $A_1A_1B_3$ occurred first in the AAB trial, then $A_1B_3A_1$ began the ABA trial, and so on. There were no breaks beyond the phrase-final silences between phrases in a block or between blocks.

Two 30-second test trials for each grammar were constructed using the same randomized blocking procedure, again with three blocks of the four test phrases per trial. Each test trial shared a randomization sequence with a trial from the opposite grammar.

Procedure—The headturn preference procedure (Kemler Nelson, Jusczyk, Mandel, Myers, Turk, & Gerken, 1995) was used. Infants sat on a caregiver’s lap in a small room. Caregivers listened to pop music through headphones and were instructed not to speak or direct the infant’s attention. During familiarization, a light in front of the infant flashed until the observer, blind to the experimental condition and deaf to the stimuli, judged the infant to be looking at it, triggering a blinking light on the left or right. When the infant looked at the side light and then away for two seconds, the center light would resume blinking, and the cycle would repeat. This continued for the duration of the familiarization music. In this stage there was no correspondence between infants’ looking behavior and the sound.

The test phase began immediately after familiarization. The lights behaved the same way, but now the sound was contingent on the infant orienting to a side light. Each time a side light began flashing and the infant oriented toward it, one of the four test trials would play, continuing until either the infant looked away for two seconds or the test trial reached its conclusion.

Results

Looking times were entered into an ANOVA with between-subjects factors age and familiarization grammar (AAB vs. ABA), and within-subjects factor test grammar (AAB vs. ABA). There was a significant effect of age ($F(1,32) = 5.94$, $p < 0.03$), with 4-month-olds looking longer, and of test grammar ($F(1,32) = 10.62$, $p < 0.005$), revealing an overall preference for AAB items. This preference did not differ between the age groups, as revealed by a nonsignificant interaction of test grammar and age ($F(1,32) = 0.74$, $p = 0.40$). The three-way interaction was significant ($F(1,32) = 5.54$, $p < 0.03$), indicating that discrimination of consistent and inconsistent test items differed by age. No other effects were significant. The 4-month-olds showed a preference for the test items that were inconsistent with familiarization ($t(17) = 2.61$, $p < 0.02$), but the 7.5-month-olds showed no preference ($t(17) = 0.33$, $p = 0.74$).

Discussion

The performance of the 7.5-month-olds replicates the findings of Marcus et al. (2007). Importantly, the significant three-way interaction, with the significant novelty preference in the 4-month-olds, suggests that the younger learners could better detect structure in chord sequences than the older learners. However, to confirm that the observed pattern was not due to any particular feature of the chord stimuli, Exp. 2 tested two new groups of infants on single-tone stimuli.

Experiment 2

In addition to replicating the pattern of results in Exp. 1, Exp. 2 employed singletone AAB and ABA sequences, to more closely parallel those used by Marcus and colleagues (2007).

Methods

Participants—Eighteen infants (6 females) between 3.5 and 4.5 months (mean 18 weeks) and eighteen infants (3 females) between 7 and 8 months (mean 33 weeks) were recruited from the Tucson area. Inclusion criteria were identical to Exp. 1. Data from four additional 4-month-olds and one additional 7-month-old was collected but was excluded from analysis due to these infants' failure to complete the minimum number of test trials.

Materials—Trials were series of AAB or ABA phrases identical in duration and construction to those in Exp. 1, with the exception that, instead of chords, single tones were used. The set of intervals represented in familiarization had no overlap with the set represented at test.

Procedures—were identical to Exp. 1.

Results

Looking times were again entered into an Age X Familiarization X Test ANOVA. There was a significant effect of age ($F(1,32) = 7.69$, $p < 0.01$), with 4-month-olds looking longer overall. Most important, the three-way interaction was significant ($F(1,32) = 4.35$, $p < 0.05$). The test grammar effect present in Exp. 1 was nonsignificant here, as were all other effects. The 4-month-olds showed a preference for the test items that were inconsistent with familiarization ($t(17) = 2.55$, $p < 0.03$), but the 7.5-month-olds showed no preference ($t(17) = 0.36$, $p = 0.71$).

Discussion

The 4-month-olds' preference for the novel grammar in Exp. 2 supports the conclusion that they are able to learn the abstract generalization defining the grammar to which they are exposed. The absence of an overall AAB preference suggests that this was a statistical fluke or an artifact of the chord stimuli used in Exp. 1, rather than a general tendency of infants listening to music. The success of the 4-month-olds in both experiments adds to the evidence that infants' ability to learn such a generalization does not rely on a language-specific symbol-manipulation mechanism.

General Discussion

In two experiments, we show that 4-month-olds but not 7.5-month-olds appear to learn AAB and ABA generalizations in chord- and tone-sequences, abstracting away from the surface elements. These findings are important for two reasons: first, the success of the 4-month-olds constitutes the first result involving AAB/ABA pattern-learning with infants younger than 5 months. Second, it appears that this abstract pattern-learning is available in music at least as early as in language. This adds to the evidence (Saffran, et al., 2007; Johnson, et al., in press; Murphy, et al., 2008) that the abstract pattern-learning reported by Marcus, et al. (1999, 2007) is not specific to language.

The reason for 7.5-month-olds' failure to learn the AAB/ABA pattern with musical elements cannot yet be uniquely determined. There are at least two classes of (non-mutually exclusive) explanation that are consistent with the data. First, general cognitive differences between 4- and 7-month-olds, coupled with relatively low-level differences in stimulus complexity between domains, could lead to different patterns of encoding. For example, 7-month-olds might segment music into larger units than do 4-month-olds, leaving the dependencies within units relatively unanalyzed. By the same logic, since language is acoustically more complex than musical tones, 7-month-olds might represent it using more fine-grained units than they use for music, which could contribute to the discrepancy between music and language observed by Marcus, et al. (2007) in infants of that age.

The second class of explanation involves learning about the relevant properties of different domains. In the case of music, attention to pitch contour and tonality could come at the expense of attention to abstract sequential dependencies. For example, 7.5-month-olds may pay more attention than 4-month-olds to rising and falling contours in music, leading to difficulty in learning an abstract generalization that requires collapsing across different contours[1]. Indeed, it has been argued that melodic contour is the single most salient aspect of music for infants (see Trehub (2001) for a review). Or perhaps the older infants have come to treat pitch as an "analog" rather than a "symbolic" dimension, carrying affective and not structural information, due to their experience with language (see Trainor, Austin and Desjardins (2000) for a discussion of affective cues in the prosody of infant-directed speech). If so, infants exposed to a language in which pitch is phonological may perform differently.

Experience with music could change infants' relationship with pitch as well. Lynch and Eilers (1992) show that as early as 6 months of age, infants are better at detecting mistunings in two Western scales than in a Javanese pélog scale. By 12-months, they perform well only in the Western major scale. This suggests some level of sensitivity to Western tonality possibly beginning to emerge as early as 6-months and certainly in place by a year. Preliminary data from our lab suggests that 7-month-olds can learn a generalization that requires melodies to end on a particular scale degree in the key (either "do" or "sol"), irrespective of the absolute pitch, an ability which would require at least representation of relative pitch, and likely some sense of the major scale.

As infants learn more about music, their ability to predict which pitches might follow at a particular point in a melody should improve. Two components of melodic prediction that have been instantiated in a Bayesian model of melody perception by Temperley (2008) are the prior expectations that small intervals are more frequent than large ones, and that notes outside the key are rare. If infants expect melodies to be biased toward smaller intervals (with few large jumps in pitch), the incidence of repetition (an interval size of 0) that is expected solely due to such a constraint would be increased. Similarly, as learners develop a sense of musical key, the set of likely tones shrinks to only those in the key. In general, the smaller the set of candidate tones, the higher the expected incidence of repetition due to chance. If infants acquire these sorts of musical expectations, they would help to "explain away" the actual incidence of exact repetitions as due to the global properties of melodic smoothness and key, rather than being due to any specific structural property involving exact repetition[2]. As such, they might be less likely to entertain a new melodic generalization that depends on exact repetition (such as the generalization that a set of melodies must follow an AAB pattern). Note, however, that this

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[1] We thank an anonymous reviewer for suggesting this explanation.

[2] The notion of "explaining away" is central to Bayesian statistical models of vision (e.g. Kersten, Mamassian and Yuille, 2004), linguistic processing (e.g. Ciaramita and Johnson. 2000), and has even been used to explain 8-month-old infants' behavior in a "statistical reasoning" scenario (Xu and Garcia, 2008). Suppose I show you that I can make a coin turn up heads ten times in a row. If you are naïve, you may begin to believe that I can influence the outcome of the flip. However, when you examine the coin carefully, you find that it is weighted toward heads. Although I am no *less* likely to be telekinetic than I was before the demonstration, the series of ten consecutive heads is much weaker evidence, since the expected proportion of heads in the *absence* of telekinesis has increased. You might even go a step further and discount coin flips as evidence for telekinesis in the future, given the knowledge that weighted coins exist. In the present context, the knowledge that large intervals and non-diatonic tones are rare would be roughly analogous to finding out that the coin is weighted. Without this knowledge, the incidence of repetitions could be taken as evidence for a structural property of melodies involving exact repetition in particular, but once the broader properties are taken into account, the evidence for the more specific property is "explained away", and its *a posteriori* probability decreases.

possibility remains speculative until the details of infants' musical knowledge are examined in more depth.

While our data does not directly distinguish between explanations concerning general cognitive changes and those concerning the accumulation of domain knowledge, hypotheses in either category are consistent with our broader point: apparent domain-specificity of a learning mechanism need not be attributed to an innately modular organization of the mind. While some genetic constraints are undoubtedly present, both previous learning and domain-general cognitive biases must be considered as potential sources of constraints on subsequent learning, whether by altering representations, attentional settings, or both.

Several specific open questions remain regarding the role of prior learning in influencing infants' pattern-learning in auditory sequences. One general question concerns the relative importance of upweighting attention to salient features, and downweighting less salient ones (see Maye, Weiss and Aslin (2008) for a discussion of this distinction in phonetic perception). Could AAB/ABA sequences be learned by 7.5-month-olds in a domain in which they have no expectations? Second, the statistics of children's input, in both language and music, must be examined in greater detail. Furthermore, if particular representational or attentional factors such as chunk size, pitch contour, or tonality play a role, it must be shown that infants employ the relevant representations. Finally, if a causal role for experience is to be demonstrated, studies that go beyond observing correlation, that actually manipulate the infant's experience, must be conducted. Although ethical concerns preclude doing so over much more than a few minutes in the domain of language, the domain of music may provide an ideal testing ground for more temporally extended manipulations.

Acknowledgements

This research was supported by an NSF Graduate Research Fellowship to Colin Dawson and NIH R01 HD042170 to LouAnn Gerken.

References

Bosch L, Sebastián-Gallés N. Simultaneous bilingualism and the perception of a language-specific vowel contrast in the first year of life. Language and Speech 2003;46:217–243. [PubMed: 14748445]

Chomsky, N. The Minimalist Program. Cambridge, MA: The MIT Press; 1995.

Ciaramita, M.; Johnson, M. Explaining away ambiguity: Learning verb selectional preference with Bayesian networks. Proceedings of the 18th International Conference on Computational Linguistics; Saarbrucken, Germany. 2000. p. 187-193.

Fodor, J. The Modularity of Mind. Cambridge, MA: The MIT Press; 1983.

Gerken L, Bollt A. Three exemplars allow at least some linguistic generalizations: Implications for generalization mechanisms. Language Learning and Development 2008;4(3):228–248.

Hannon EE, Trehub SE. Tuning into musical rhythms: Infants learn more readily than adults. Proceedings of the National Academy of Sciences 2005;102(35):12639–12643.

Jacobs RA. Nature, nurture, and the development of functional specializations: A computational approach. Psychonomic Bulletin and Review 1997;4:299–309.

Jacobs RA. Computational studies of the development of functionally specialized neural modules. Trends in Cognitive Science 1999;3:31–38.

Johnson SP, Fernandes KJ, Frank MC, Kirkham NZ, Marcus GF, Rabagliati H, Slemmer JA. Abstract rule learning for visual sequences in 8- and 11-month-olds. Infancy. in press

Kanwisher, N.; McDermott, J.; Chun, MM. The Fusiform Face Area: A Module in Human Extrastriate Cortex Specialized for Face Perception. In: Cacioppo, JT., et al., editors. Foundations in Social Neuroscience. Cambridge, MA: MIT Press; 2002.

Karmiloff-Smith, A. Beyond Modularity: A Developmental Perspective on Cognitive Science. Cambridge, MA: The MIT Press; 1992.

Kemler Nelson DG, Jusczyk PW, Mandel DR, Myers J, Turk A, Gerken LA. The headturn preference procedure for testing auditory perception. Infant Behavior and Development 1995;18:111–116.

Kersten D, Mamassian P, Yuille A. Object perception as Bayesian inference. Annual Review Psychology 2004;55:271–304.

Liberman AM, Mattingly IG. The motor theory of speech perception revised. Cognition 1985;21:1–36. [PubMed: 4075760]

Lynch MP, Eilers RE. A study of perceptual development for musical tuning. Perception and Psychophysics 1992;52(6):599–608. [PubMed: 1287565]

Marcus G, Fernandes K, Johnson S. Infant Rule-Learning Facilitated by Speech. Psychological Science 2007;18:387–391. [PubMed: 17576276]

Marcus GF, Vijayan S, Rao SB, Vishton PM. Rule learning by seven-month-old infants. Science 1999;283:77–80. [PubMed: 9872745]

Marr, D. Vision: A Computational Investigation into the Human Representation and Processing of Visual Information. New York: Henry Holt and Co., Inc.; 1982.

Maye J, Weiss DJ, Aslin RN. Statistical phonetic learning in infants: facilitation and feature generalization. Developmental Science 2008;11(1):122–134. [PubMed: 18171374]

Maye J, Werker J, Gerken LA. Infant sensitivity to distributional information can affect phonetic discrimination. Cognition 2002;82:101–111.

Murphy RA, Mondragon E, Murphy VA. Rule learning by rats. Science 2008;319:1849–1851. [PubMed: 18369151]

Pascalis O, de Haan M, Nelson CA. Is face processing species-specific during the first year of life? Science 2002;296:1321–1323. [PubMed: 12016317]

Pinker, S. How the Mind Works. New York: W.W Norton & Co.; 1997.

Saffran J. Statistical language learning: Mechanisms and constraints. Current Directions in Psychological Science 2003;12:110–114.

Saffran JR, Griepentrog GJ. Absolute pitch in infant auditory learning: Evidence for developmental reorganization. Developmental Psychology 2001;37:74–85. [PubMed: 11206435]

Saffran JR, Pollack SD, Seibel RL, Shkolnik A. Dog is a dog is a dog: Infant rule learning is not specific to language. Cognition 2007;105:669–680. [PubMed: 17188676]

Scholl BJ, Leslie AM. Modularity, Development and 'Theory of Mind'. Mind and Language 1999;14:131–153.

Temperley D. A probabilistic model of melody perception. Cognitive Science: A Multidisciplinary Journal 2008;32(2):418–444.

Trainor L, Austin C, Desjardins P. Is infant-directed speech prosody a result of the emotional expression of emotion? Psychological Science 2000;11(3):188–195. [PubMed: 11273402]

Trainor L, Trehub S. A comparison of infants' and adults' sensitivity to Western musical structure. Journal of Experimental Psychology: Human Perception and Performance 1992;18:394–402. [PubMed: 1593226]

Trehub, SE. Annals of the New York Academy of Sciences. New York: New York Academy of Sciences; 2001. Musical predispositions in infancy.

Werker JF, Tees RC. Cross-language speech perception: evidence for perceptual reorganization during the first year of life. Infant Behavior and Development 1984;7:49–63.

Xu F, Garcia V. Intuitive statistics by 8-month-old infants. Proceedings of the National Academy of Sciences of the United States of America 2008;105(13):5012–5015. [PubMed: 18378901]

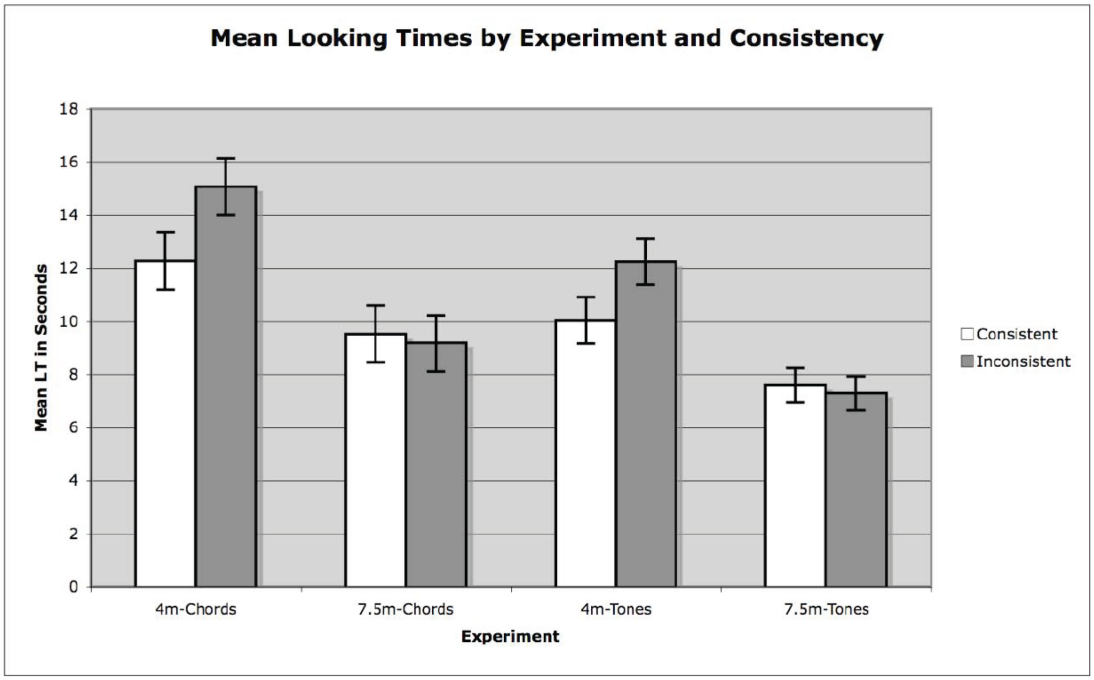

Figure 1.
Experimental Data