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Brief article

Rule learning by cotton-top tamarins

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Abstract

Previous work suggests that human infants are capable of rapidly generalizing patterns that have been characterized as abstract algebraic rules (*Science 283* (1999) 77), a process that may play a pivotal role in language acquisition. Here we explore whether this capacity is uniquely human and evolved specifically for the computational problems associated with language, or whether this mechanism is shared with other species, and therefore evolved for problems other than language. We used the same materials and methods that were originally employed in tests of human infants to assess whether cotton-top tamarin monkeys can extract abstract algebraic rules. Specifically, we habituated subjects to sequences of consonant–vowel syllables that followed one of two patterns, AAB (e.g. wi wi di) or ABB (e.g. de we we). Following habituation, we presented subjects with two novel test items, one with the same pattern as that presented during habituation and one with a different pattern. Like human infants, tamarins were more likely to dishabituate to the test item with a different pattern. We conclude that the capacity to generalize rule-like patterns, at least at the level demonstrated, did not evolve specifically for language acquisition, though it remains possible that infants might use such rules during language acquisition. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

All mimsy were the borogoves. When Lewis Carroll wrote these words, he illustrated one of the basic hallmarks of human cognition, the ability to extend abstract structure to new instances. This ability has its roots early in life. Using the familiarization preference paradigm (Jusczyk, 1997; Saffran, Aslin, & Newport, 1996), Marcus, Vijayan, Bandi Rao,

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and Vishton (1999) asked whether 7-month-old infants could detect the similarity between patterns like *la ta ta* and *ga na na* and generalize it to novel sounding, but comparably structured patterns like *wo fe fe*. Infants were habituated for 2 min to a set of training sentences, and then tested on new sentences, all of which were made up of new words, half with the same abstract structure, half with a different abstract structure. The dependent measure was looking time: words are paired with flashing lights, with looking time used as an indirect measure of attention to the auditory materials. Results showed that infants looked longer to test items with a different pattern than to test items that shared the same abstract structure as the training material.

Marcus et al. (1999) described the infant's extraction of information from the familiarization corpus as a process of learning "algebraic rules" because the materials tested could be described in terms of algebra-like relations between abstract variables. These results have attracted considerable attention from linguists, computer scientists, and developmental psychologists (Altmann & Dienes, 1999; Christiansen & Curtin, 1999; Eimas, 1999; Marcus, 1999a,b,c, 2001; Marcus et al., 1999; McClelland & Plaut, 1999; Negishi, 1999; Seidenberg & Elman, 1999; Shastri, 1999; Shultz, 1999). Although much of the discussion has been about the nature of the mechanism that underlies the infants' ability to generalize (e.g. whether or not the infants' generalizations depended on "algebraic rules", or on some other form of pattern extraction, an issue that lies outside of the scope of the current report), another important question, thus far unaddressed, is whether the ability to spontaneously extract and rapidly generalize such abstract patterns distinguishes humans from other animals. This question lies at the core of what makes human cognition unique. Earlier studies are suggestive, but not definitive. For example, many animals, ranging from honey bees to chimpanzees, perform well on match-to-sample experiments. In a match-to-sample study, an animal must learn a rule such as "Select the comparison stimulus that looks like the sample stimulus." Under these conditions, if the animal learns this rule with one set of stimuli, say those varying in color, it should readily transfer to a new set that vary in (say) shape. In a recent study by Giurfa, Zhang, Jenett, Menzel, and Srinivasan (2001), honeybees were first trained to find food in a Y-maze. At the entrance to the maze was a color patch such as blue and on each branch of the maze was one identical patch (i.e. blue) and one different patch (e.g. yellow); the food reward was always associated with the matching patch. The bees learned to find the food regardless of whether the blue patch was on the right or left branch; they also learned to generalize to different patterns and even other modalities such as odors. Such work suggests that the capacity to understand sameness at some abstract level may extend throughout the animal kingdom. But animals in these experiments are all heavily trained. In contrast, the infants in the Marcus et al. experiments acquired a rule after a very brief exposure, just 2 min of strings like *la ta la*, without any reward or training. Can animals draw such rapid inferences in the absence of training?

The infant experiments also differed from traditional match-to-sample experiments in that the test items were not only novel, but composed entirely of novel words that were designed to be dissimilar to those in training. For example, the test words varied in the feature of voicing (e.g. if the "A" word was voiced, the "B" word was unvoiced), whereas the familiarization words were all voiced, so the familiarization provided no direct information about the relation between voiced and unvoiced consonants. Can non-human animals extract abstract structure under the same stringent conditions, and in the absence of training? The ability to generalize rapidly is fundamental to human cognition – is it also unique to humans?

To address this problem, we present the results of an experiment using cotton-top tamarin monkeys and the same methods and materials employed by Marcus and colleagues in their original experiment. Tamarins are an ideal species in which to explore this problem because the methods (i.e. habituation–discrimination) have already been successfully employed to test both speech perception (Hauser, Newport, & Aslin, 2001; Ramus, Hauser, Miller, Morris, & Mehler, 2000) and recognition of species-typical vocalizations (Weiss, Garibaldi, & Hauser, 2001). Of particular importance to the present work, earlier experiments have already shown that cotton-top tamarins can extract words from a continuous stream of consonant–vowel (CV) syllables using conditional probabilities (Hauser et al., 2001), a result that directly parallels those obtained by Saffran et al. (1996) with human infants, an experiment that resembles ours in structure, though not in materials.

2. Method

2.1. Subjects

We tested 14 adult cotton-top tamarins (*Saguinus oedipus*), eight females and six males. This species is native to the rainforests of Colombia. All subjects were born in captivity at the New England Regional Primate Research Center, Southborough, MA or the Primate Cognitive Neuroscience Lab, Harvard University. Animals are housed in social groups consisting of a mated pair, and in some cases their offspring.

All subjects have experienced playback experiments, including studies involving their species-typical vocalizations (Ghazanfar, Flombaum, Miller, & Hauser, 2001; Miller, Dibble, & Hauser, 2001) as well as natural or synthetic human speech (Hauser et al., 2001; Ramus et al., 2000). All of these experiments have been conducted in the same testing environment and thus, the tamarins readily move in and out of their home cage and into this test area, remaining calm for approximately 30 min.

2.2. Stimuli

We used the same material that Marcus and colleagues presented to 7-month-old infants in their third experiment. Specifically, subjects were habituated to either a sample of tokens matching the AAB pattern or the ABB pattern. These tokens consisted of CV syllables and were created with a speech synthesizer available at www.bell-labs.com/project/tts/voices-java.html. The 16 strings ("sentences" in Marcus et al.) available in the ABB corpus were: "ga ti ti", "ga na na", "ga gi gi", "li na na", "li ti ti", "li gi gi", "li la la", "ni gi gi", "ni ti ti", "ni na na", "ni la la", "ta la la", "ta ti ti", "ta na na", and "ta gi gi"; the AAB sentences were made out of the same CV syllables or "words". We used a contrast between ABB and AAB because unlike the first experiments run on infants involving ABA versus ABB, there is no possibility of using simple duplication to extract the relevant distinction. Based on studies of non-human primate hearing, and other work on speech segmentation (Hauser et al., 2001), we were confident that tamarins could hear the material presented, and presumably make the perceptual distinction between different CV syllables. Moreover, the overall length of a sentence (i.e. approximately 2–3 s) is comparable to the material presented in other studies of speech perception with tamarins (Hauser et al., 2001; Ramus et al., 2000).

2.3. Design and experimental procedure

We ran seven subjects on a habituation series involving the ABB pattern and seven on the AAB pattern. Once habituated, subjects were presented with two test trials. Each token presented in the test trial was acoustically novel in that it consisted of CV syllables that had not been presented in the habituation corpus. On the first test trial, half of our subjects received the same pattern as presented in the habituation series, while the other half received the different pattern.

A session ran as follows. We removed a subject from its home cage and transported it to the test room. The subject was placed in a soundproof chamber with a speaker concealed up and to the left of the subject's back. Once the door was closed, we observed the subject's position within the cage by means of a camera attached to a monitor outside the chamber. To maximize the probability of obtaining an unambiguous response, we presented stimuli while the subject was still and faced 180 degrees away from the concealed speaker; this is the procedure used in all previous playback experiments on this species. When the subject's position met our criterion, we played back the first token within the habituation series. For each subject, the presentation of tokens within the habituation series was randomized. Consecutive presentations of tokens within both the habituation and test series were separated by a minimum of 10 s and a maximum of 60 s. The habituation series ended when we scored three consecutive no responses. The test series immediately followed consisting of two test trials, one with the same pattern and one with a different pattern.

We did not run subjects who failed to leave their home room cage on the day of testing; those who jumped around the test cage and failed to sit quietly during the habituation series were rerun (one for ABB, two for AAB). The dependent measure was an orienting response to a test stimulus presented from a concealed loudspeaker (Hauser et al., 2001; Ramus et al., 2000). We scored the subject as responding if it turned and looked in the direction of the speaker either within 2 s after the presentation of the stimulus or if the response occurred during the stimulus and was then maintained until its completion; responses occurring during the presentation and ending before its completion were considered "no responses" because of the importance of having the entire sequence of CV syllables heard.

All experiments were videotaped. Although we scored the trials on-line, we re-scored the last three habituation trials and the two test trials by digitizing each trial, and scoring the response blind to condition (see Hauser et al., 2001). Furthermore, and following the procedure used in all other playbacks on tamarins, two experimenters independently scored 20 trials and obtained high inter-observer reliabilities ($r = 0.89$). In these experiments, the on-line scoring for all habituation trials precisely matched those scored blind and thus, we did not have to rerun any sessions. Only five test trials were scored differently on-line and off-line, and we used the off-line response in our analyses.

3. Results

Subjects differed with respect to the number of trials to habituation (range 7–36). However, and as revealed in Fig. 1, the number of trials to habituation did not differ between subjects presented with AAB (mean = 15.57, SE = 3.84) and those presented with ABB (mean = 18.00, SE = 4.36; $F = 0.18$, d.f. = 1, 12; $P = 0.68$).

As mentioned in Section 2, all subjects started the test trials having achieved the same level of habituation (i.e. three consecutive no response trials). When presented with the two test trials, however, subjects were more likely to respond by orienting toward the speaker when the pattern changed from the habituation series than when it stayed the same (Fig. 2; $\chi^2 = 5.60$, d.f. = 1, $P < 0.02$). Thus, although the actual sequence of sounds presented was novel on both test trials, the tamarins' response was mediated by differences in the pattern of syllables rather than their acoustics per se.

4. Discussion

On the basis of less than 40 trials of exposure, and with no reinforcement for responding, cotton-top tamarins were able to discriminate between novel strings of two different structures, one familiar, the other unfamiliar. One hypothesis (Marcus et al., 1999) is that the ability to make such discriminations depends on the ability to acquire and recognize abstract relations between variables, or “rules”. Although the “rule” hypothesis remains controversial (see earlier references), we maintain that it is the best available (Marcus, 2001) and for the sake of exposition, we provisionally adopt it here. Whether infants are extracting rules or doing some other form of pattern recognition, it is clear that the generalizations they draw are fast and accurate.

Our results show that tamarins are capable of similar rapid generalizations, thus raising

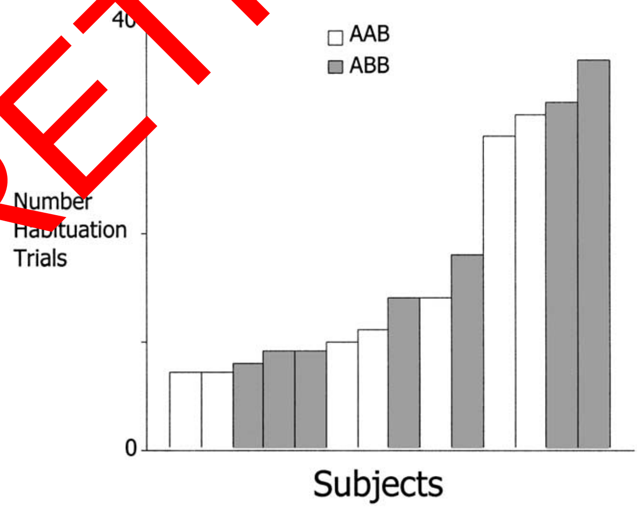

Fig. 1. Number of trials to habituation for subjects tested with either AAB or ABB.

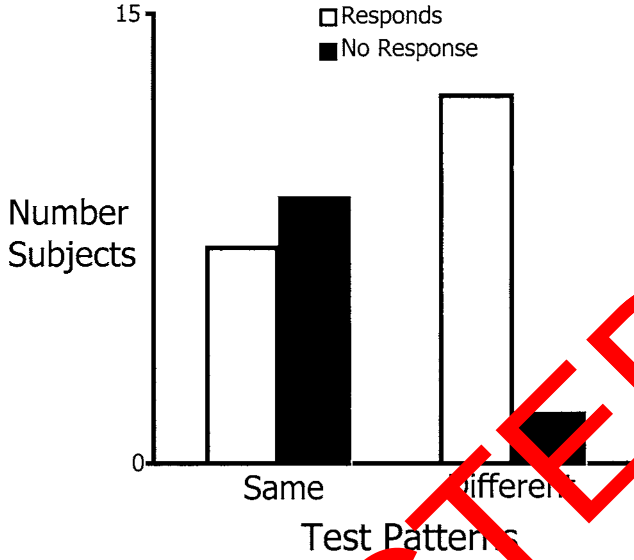

Fig. 2. Tamarins' responses in the test trials. White bars indicate the number of subjects responding by orienting toward the speaker, while gray bars indicate the number of subjects showing no orienting response.

interesting questions for ongoing debates about what makes language learning so special (Pinker, 1994). If tamarins can extract these patterns, why can't they learn language? Certainly, the ability to extract abstract patterns is one of the hallmarks of language, as the ability to judge the grammaticality of Jabberwocky makes clear. The ability to make infinite use of finite media (Chomsky, 1957; Humboldt, 1836; Pinker, 1994) surely depends on some kind of capacity to extract and generalize abstract templates.

But while the ability to learn rules may be necessary for language – most theories of language represent linguistic knowledge through rules or something equivalent – it cannot be sufficient. The ability to use a language must depend on more than just the ability to represent, extract and generalize regularities; it must also depend on the ability to maintain a lexicon, the ability to form semantic representations and link them with syntactic configurations, and the ability to represent hierarchical structure (Chomsky, 1957). Many theories of language also suggest that the ability to learn a language likely also depends on some set of innate constraints. Part of universal grammar may tell a language learner that languages are made up of rules, but the rest of universal grammar may inform the learner about the nature of *which* rules are possible in human language. Rules of human languages likely are rules that constrain relationships between hierarchical linguistic objects such as noun phrases and verb phrases. To date, it is unknown whether any non-human animal is capable of extracting this type of hierarchical information. Furthermore, even if this type of information can be extracted, it is unknown whether the constraints that operate for human language would also constrain acquisition for non-human animals.

Learning a language also likely depends on the ability to form reasonable guesses about what other people are talking about, what their beliefs and intentions are. To date, there is no evidence that monkeys have a theory of mind (Cheney & Seyfarth, 1990). And although there are some studies showing that chimpanzees may have the rudiments of a theory of mind (Hare, Call, Agnetta, & Tomasello, 2000; Hare, Call, & Tomasello, 2001; Premack & Woodruff, 1978), other studies suggest that they do not (Povinelli & Eddy, 1996; Tomasello & Call, 1997).

To be able to represent the rules of language is not enough. One must draw a distinction between the ability to learn some rules and the ability to learn the right rules. Our view is that the ability to learn rules is a domain-general mechanism that is readily available to a wide variety of animals, able to participate in a wide variety of domain-specific and domain-general computations. We suspect, in fact, that the ability to learn a rule depends on some particular (as yet undiscovered) type of neural circuit that is quite common throughout the brain. Devices for using rules may be a bit like memory in this regard. Memory is neither special to humans nor special to any particular cognitive domain (although there may be several types of memory), but it is an essential component of virtually all cognitive systems. Similarly, the abilities to extract statistical regularities (Saffran et al., 1996) and abstract algebra-like patterns (Marcus et al., 1999) may be oft-used cognitive building blocks, building blocks that are sometimes used in domain-general mechanisms, sometimes used in domain-specific mechanisms. Although our results do not answer the riddles of innateness and domain-specificity, they do take us one step closer to an understanding of what makes human cognition special.

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