



## 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 (le 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 Published by Elsevier Science B.V.

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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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91 and Vishton (1999) asked whether 7-month-old infants could detect the similarity between 136  
 92 patterns like *la ta ta* and *ga na na* and generalize it to novel sounding, but comparably 137  
 93 structured patterns like *wo fe fe*. Infants were habituated for 2 min to a set of training 138  
 94 sentences, and then tested on new sentences, all of which were made up of new words, half 139  
 95 with the same abstract structure, half with a different abstract structure. The dependent 140  
 96 measure was looking time: words are paired with flashing lights, with looking time used as 141  
 97 an indirect measure of attention to the auditory materials. Results showed that infants 142  
 98 looked longer to test items with a different pattern than to test items that shared the same 143  
 99 abstract structure as the training material. 144

100 Marcus et al. (1999) described the infant's extraction of information from the familiar- 145  
 101 ization corpus as a process of learning "algebraic rules" because the materials tested could 146  
 102 be described in terms of algebra-like relations between abstract variables. These results 147  
 103 have attracted considerable attention from linguists, computer scientists, and developmen- 148  
 104 tal psychologists (Altmann & Dienes, 1999; Christiansen & Curtin, 1999; Eimas, 1999; 149  
 105 Kuehne et al., 1999; Marcus, 1999a,b,c, 2001; Marcus & Bandi Rao, 1999; Marcus et al., 150  
 106 1999; McClelland & Plaut, 1999; Negishi, 1999; Seidenberg & Elman, 1999; Shastri, 151  
 107 1999; Shultz, 1999). Although much of the discussion has been about the nature of the 152  
 108 mechanism that underlies the infants' ability to generalize (e.g. whether or not the infants' 153  
 109 generalizations depended on "algebraic rules", or on some other form of pattern extrac- 154  
 110 tion, an issue that lies outside of the scope of the current report), another important 155  
 111 question, thus far unaddressed, is whether the ability to spontaneously extract and rapidly 156  
 112 generalize such abstract patterns distinguishes humans from other animals. This question 157  
 113 lies at the core of what makes human cognition unique. Earlier studies are suggestive, but 158  
 114 not definitive. For example, many animals, ranging from honey bees to chimpanzees, 159  
 115 perform well on match-to-sample experiments. In a match-to-sample study, an animal 160  
 116 must learn a rule such as "Select the comparison stimulus that looks like the sample 161  
 117 stimulus." Under these conditions, if the animal learns this rule with one set of stimuli, 162  
 118 say those varying in color, it should readily transfer to a new set that vary in (say) shape. In 163  
 119 a recent study by Giurfa, Zhang, Jenett, Menzel, and Srinivasan (2001), honeybees were 164  
 120 first trained to find food in a Y-maze. At the entrance to the maze was a color patch such as 165  
 121 blue and on each branch of the maze was one identical patch (i.e. blue) and one different 166  
 122 patch (e.g. yellow); the food reward was always associated with the matching patch. The 167  
 123 bees learned to find the food regardless of whether the blue patch was on the right or left 168  
 124 branch; they also learned to generalize to different patterns and even other modalities such 169  
 125 as odors. Such work suggests that the capacity to understand sameness at some abstract 170  
 126 level may extend throughout the animal kingdom. But animals in these experiments are all 171  
 127 heavily trained. In contrast, the infants in the Marcus et al. experiments acquired a rule 172  
 128 after a very brief exposure, just 2 min of strings like *la ta la*, without any reward or 173  
 129 training. Can animals draw such rapid inferences in the absence of training? 174

130 The infant experiments also differed from traditional match-to-sample experiments in 175  
 131 that the test items were not only novel, but composed entirely of novel words that were 176  
 132 designed to be dissimilar to those in training. For example, the test words varied in the 177  
 133 feature of voicing (e.g. if the "A" word was voiced, the "B" word was unvoiced), whereas 178  
 134 the familiarization words were all voiced, so the familiarization provided no direct infor- 179  
 135 mation about the relation between voiced and unvoiced consonants. Can non-human 180

181	animals extract abstract structure under the same stringent conditions, and in the absence	226
182	of training? The ability to generalize rapidly is fundamental to human cognition – is it also	227
183	unique to humans?	228
184	To address this problem, we present the results of an experiment using cotton-top	229
185	tamarin monkeys and the same methods and materials employed by Marcus and collea-	230
186	gues in their original experiment. Tamarins are an ideal species in which to explore this	231
187	problem because the methods (i.e. habituation–discrimination) have already been success-	232
188	fully employed to test both speech perception (Hauser, Newport, & Aslin, 2001; Ramus,	233
189	Hauser, Miller, Morris, & Mehler, 2000) and recognition of species-typical vocalizations	234
190	(Weiss, Garibaldi, & Hauser, 2001). Of particular importance to the present work, earlier	235
191	experiments have already shown that cotton-top tamarins can extract words from a contin-	236
192	uous stream of consonant–vowel (CV) syllables using conditional probabilities (Hauser et	237
193	al., 2001), a result that directly parallels those obtained by Saffran et al. (1996) with human	238
194	infants, an experiment that resembles ours in structure, though not in materials.	239
195		240
196		241
197	<b>2. Method</b>	242
198		243
199	<i>2.1. Subjects</i>	244
200		245
201	We tested 14 adult cotton-top tamarins ( <i>Saguinus oedipus</i> ), eight females and six males.	246
202	This species is native to the rainforests of Colombia. All subjects were born in captivity at	247
203	the New England Regional Primate Research Center, Southborough, MA or the Primate	248
204	Cognitive Neuroscience Lab, Harvard University. Animals are housed in social groups	249
205	consisting of a mated pair, and in some cases, their offspring.	250
206	All subjects have experience in playback experiments, including studies involving their	251
207	species-typical vocalizations (Ghazanfar, Flombaum, Miller, & Hauser, 2001; Miller,	252
208	Dibble, & Hauser, 2001) as well as natural or synthetic human speech (Hauser et al.,	253
209	2001; Ramus et al., 2000). All of these experiments have been conducted in the same	254
210	testing environment, and thus, the tamarins readily move in and out of their home cage and	255
211	into this test area, remaining calm for approximately 30 min.	256
212		257
213	<i>2.2. Stimuli</i>	258
214		259
215	We used the same material that Marcus and colleagues presented to 7-month-old infants	260
216	in their third experiment. Specifically, subjects were habituated to either a sample of	261
217	tokens matching the AAB pattern or the ABB pattern. These tokens consisted of CV	262
218	syllables and were created with a speech synthesizer available at <a href="http://www.bell-labs.com/project/tts/voices-java.html">www.bell-labs.com/</a>	263
219	project/tts/voices-java.html. The 16 strings (“sentences” in Marcus et al.) available in	264
220	the ABB corpus were: “ga ti ti”, “ga na na”, “ga gi gi, ga”, “la la, li na na”, “li ti ti”,	265
221	“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”,	266
222	and “ta gi gi”; the AAB sentences were made out of the same CV syllables or “words”. We	267
223	used a contrast between ABB and AAB because unlike the first experiments run on infants	268
224	involving ABA versus ABB, there is no possibility of using simple duplication to extract	269
225	the relevant distinction. Based on studies of non-human primate hearing, and other work	270
	on speech segmentation (Hauser et al., 2001), we were confident that tamarins could hear	

271 the material presented, and presumably make the perceptual distinction between different 316  
 272 CV syllables. Moreover, the overall length of a sentence (i.e. approximately 2–3 s) is 317  
 273 comparable to the material presented in other studies of speech perception with tamarins 318  
 274 (Hauser et al., 2001; Ramus et al., 2000). 319  
 275 320

276 *2.3. Design and experimental procedure* 321  
 277 322

278 We ran seven subjects on a habituation series involving the ABB pattern and seven on 323  
 279 the AAB pattern. Once habituated, subjects were presented with two test trials. Each token 324  
 280 presented in the test trial was acoustically novel in that it consisted of CV syllables that had 325  
 281 not been presented in the habituation corpus. On the first test trial, half of our subjects 326  
 282 received the same pattern as presented in the habituation series, while the other half 327  
 283 received the different pattern. 328

284 A session ran as follows. We removed a subject from its home cage and transported it to 329  
 285 the test room. The subject was placed in a soundproof chamber with a speaker concealed 330  
 286 up and to the left of the subject's back. Once the door was closed, we observed the 331  
 287 subject's position within the cage by means of a camera attached to a monitor outside 332  
 288 the chamber. To maximize the probability of obtaining an unambiguous response, we 333  
 289 presented stimuli while the subject was still and faced 180° away from the concealed 334  
 290 speaker; this is the procedure used in all previous playback experiments on this species. 335  
 291 When the subject's position met our criterion, we played back the first token within the 336  
 292 habituation series. For each subject, the presentation of tokens within the habituation 337  
 293 series was randomized. Consecutive presentations of tokens within both the habituation 338  
 294 and test series were separated by a minimum of 10 s and a maximum of 60 s. The 339  
 295 habituation series ended when we scored three consecutive no responses. The test series 340  
 296 immediately followed consisting of two test trials, one with the same pattern and one with 341  
 297 a different pattern. 342

298 We did not run subjects who failed to leave their home room cage on the day of testing; 343  
 299 those who jumped around the test cage and failed to sit quietly during the habituation 344  
 300 series were rerun (one for ABB, two for AAB). The dependent measure was an orienting 345  
 301 response to a test stimulus presented from a concealed loudspeaker (Hauser et al., 2001; 346  
 302 Ramus et al., 2000). We scored the subject as responding if it turned and looked in the 347  
 303 direction of the speaker either within 2 s after the presentation of the stimulus or if the 348  
 304 response occurred during the stimulus and was then maintained until its completion; 349  
 305 responses occurring during the presentation and ending before its completion were consid- 350  
 306 ered "no responses" because of the importance of having the entire sequence of CV 351  
 307 syllables heard. 352

308 All experiments were videotaped. Although we scored the trials on-line, we re-scored 353  
 309 the last three habituation trials and the two test trials by digitizing each trial, and scoring 354  
 310 the response blind to condition (see Hauser et al., 2001). Furthermore, and following the 355  
 311 procedure used in all other playbacks on tamarins, two experimenters independently 356  
 312 scored 20 trials and obtained high inter-observer reliabilities ( $r = 0.89$ ). In these experi- 357  
 313 ments, the on-line scoring for all habituation trials precisely matched those scored blind 358  
 314 and thus, we did not have to rerun any sessions. Only five test trials were scored differently 359  
 315 on-line and off-line, and we used the off-line response in our analyses. 360

### 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

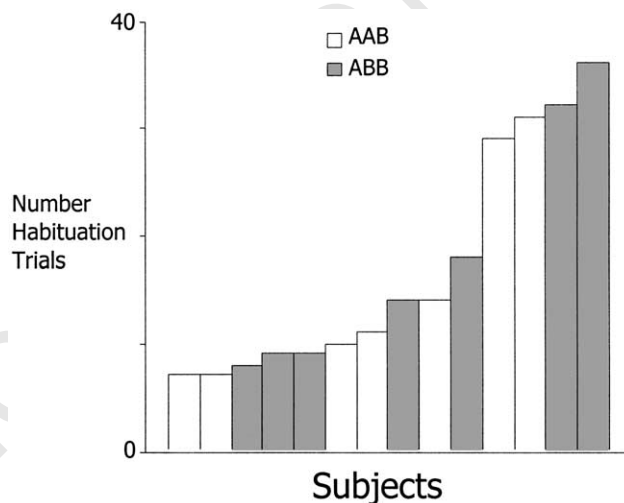


Fig. 1. Number of trials to habituation for subjects tested with either AAB or ABB.

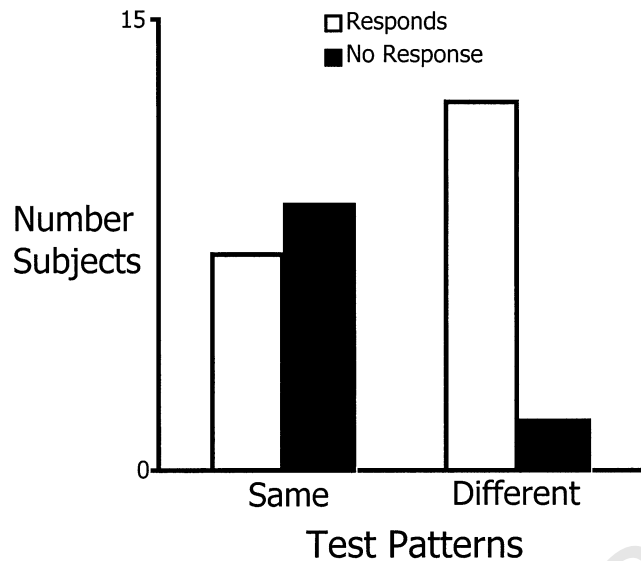


Fig. 2. Tamarins' responses in the test trials. White bars indicate the number of subjects responding by orienting toward the speaker, while gray bars indicate the number of subjects showing no orienting response.

interesting questions for ongoing debates about what makes language learning so special (Elman et al., 1996; 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

541 what other people are talking about, what their beliefs and intentions are. To date, there is 586  
 542 no evidence that monkeys have a theory of mind (Cheney & Seyfarth, 1990). And although 587  
 543 there are some studies showing that chimpanzees may have the rudiments of a theory of 588  
 544 mind (Hare, Call, Agnetta, & Tomasello, 2000; Hare, Call, & Tomasello, 2001; Premack 589  
 545 & Woodruff, 1978), other studies suggest that they do not (Povinelli & Eddy, 1996; 590  
 546 Tomasello & Call, 1997). 591

547 To be able to represent the rules of language is not enough. One must draw a distinction 592  
 548 between the ability to learn some rules and the ability to learn the right rules. Our view is 593  
 549 that the ability to learn rules is a domain-general mechanism that is readily available to a 594  
 550 wide variety of animals, able to participate in a wide variety of domain-specific and 595  
 551 domain-general computations. We suspect, in fact, that the ability to learn a rule depends 596  
 552 on some particular (as yet undiscovered) type of neural circuit that is quite common 597  
 553 throughout the brain. Devices for using rules may be a bit like memory in this regard. 598  
 554 Memory is neither special to humans nor special to any particular cognitive domain 599  
 555 (although there may be several types of memory), but it is an essential component of 600  
 556 virtually all cognitive systems. Similarly, the abilities to extract statistical regularities 601  
 557 (Saffran et al., 1996) and abstract algebra-like patterns (Marcus et al., 1999) may be 602  
 558 oft-used cognitive building blocks, building blocks that are sometimes used in domain- 603  
 559 general mechanisms, sometimes used in domain-specific mechanisms. Although our 604  
 560 results do not answer the riddles of innateness and domain-specificity, they do take us 605  
 561 one step closer to an understanding of what makes human cognition special. 606  
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 570 Animal Care Committee (Assurance of Compliance A3598-01; Tamarin Assurance of 615  
 571 Compliance 92-16; March 25, 2001). 616  
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