Revisiting Fitch and Hauser's Observation That Tamarin Monkeys Can Learn Combinations Based on Finite-State Grammar

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INTRODUCTION

In a groundbreaking work, Fitch and Hauser (2004) compared artificial grammar learning between human and cotton-top tamarins (Saguinus oedipus) using finite-state grammar (FSG) and phrase-structure grammar (PSG) types. They found that while humans are able to learn both grammar types, the tamarin monkeys could only learn combinations based on FSG. FSGs process linearly ordered strings whose structure resorts to strictly adjacent steps. Examples of FSGs are $A^n$ and $(AB)^n$, where $n$ indicates the number of times $A$ and $AB$ are repeated, and $A^nB^m$, where $n \neq m$. On the other hand, PSGs are not limited to adjacency. This allows PSGs to match the number of units repeated in each series generated, as in the sequence $A^nB^m$, where the number of $A$s matches the number of $B$s (Balari et al., 2011; Longa, 2013). The non-adjacent relations in PSGs are made possible by hierarchical structures that relate items at a distance. Since PSGs require hierarchical structure, F&H conclude that while humans can generate them, tamarins cannot, thus limiting their system to sequences based strictly on adjacent dependency, that is, FSG. There is no doubt that human language requires a grammar more powerful than FSG (Chomsky, 1956, 1959). In this article, I will take up F&H's assumption that their experiments showed that the tamarin monkeys are capable of learning sequences based on FSG. While their stimuli appear to approximate an FSG, in reality they do not, except trivially. Hence, their conclusion that tamarins are capable of FSG is at best weak. This casts doubt on using the Chomsky hierarchy for describing the learning behavior of nonhuman primates. Furthermore, unlike humans, who are exposed continuously to natural speech that requires a grammar more powerful than FSG, monkeys in nature are never exposed to verbal behavior that reflects FSG in any meaningful sense. It would therefore be surprising if they exhibit mastery of FSG combinations, which are entirely outside their natural experience.

FITCH AND HAUSER’S EXPERIMENTS

In F&H’s experiments, the stimuli were composed of two categories: in one category are female utterances artificially synthesized into discrete consonant-vowel syllables ($pa$, $li$, $mo$, $nu$, $ka$ . . .), and in the other are male utterances similarly synthesized into discrete syllables that differed from the female syllables ($ba$, $di$, $yo$, $tu$, $no$ . . .). The male/female syllables also differ distinctly in pitch as well as in other acoustic variables. For FSG, a syllable from one category (A) is followed by a syllable from the other category (B) (e.g., $no$). Similar A-B combinations with different syllables were played in sequence, A-B, A-B, A-B. This is a straightforward Markovian system in which a given automaton is carried from one finite state [n] to the next state [n+1]. F&H demonstrated that cotton-top tamarin monkeys can learn $(AB)^n$. For PSG, three syllables from one category were played, followed by three syllables from the other category: A-A-A-B-B-B. FSG cannot generate this structure...
without incurring significant cost because the operation depends on non-adjacent information. As F&H note, the first “A” predicts the occurrence of the final “B”, and the second “A” predicts the second “B”, and the final “A” predicts the first “B.” This combination reflects a formal grammar higher on the Chomsky hierarchy (Chomsky, 1956)—PSG, which requires hierarchical relations. The tamarin’s ability to learn fails completely when presented with the sequence A^B^2 generated by PSG. On the other hand, humans readily learn both types of sequences. F&H conclude that the crucial difference is that while humans can generate hierarchical structures that can create non-adjacent dependencies, tamarins are unable to do so, thus limiting their system to adjacent relations. This is an important study for distinguishing human and nonhuman primate learning abilities. The question is, what precisely is the difference? While humans are capable of learning combinations based on a formal grammar more powerful than FSG, I will take issue with F&H’s assumption that what we see with tamarins is an ability to learn combinations based on FSG.\(^1\)

Their so-called FSG is the binary combination, AB. This is FSG only trivially. As I will show, in nature, monkeys are exposed most commonly to a combination of one, but we do see instances of a dual combination. The point is that we don’t see anything that exceeds two, which would be surprising if the monkeys are capable of FSG.\(^2\)

**QUESTIONING WHETHER TAMARINS CAN LEARN COMBINATIONS BASED ON FSG**

In natural settings, nonhuman primate calls are typically isolated units. The alarm calls of the vervet monkey (Strulskaker, 1967; Seyfarth et al., 1980a,b) is one such system. Vervet monkeys (Chlorocebus pygerythrus) give a distinct call when they encounter a leopard, another when they see an eagle, and a third when they come across a snake. They never combine two calls to produce a new call. This is what Miyagawa and Clarke (2019) call the System of One, and it is the predominant system for alarm calls. This leads to the question, what do we make of the demonstrated ability of tamarins to be able to learn A-B sequences?

**SYSTEM OF TWO**

Some Old World monkeys such as the Guenons of Africa produce utterances that Miyagawa and Clarke (2019), based on much prior research, analyzed as being composed of two items. A key observation is that this binary system is just that—binary. One never sees a combination that begins A, B, then goes to C, or returns to A. This is a fundamentally different behavior from what F&H would predict, because a sequence of A-B-C or A-B-A is possible in FSG. Below, I will demonstrate this binary nature using the system employed by putty-nosed monkeys (Cercopithecus nictitans).

There are two main alarm calls associated with the putty-nosed monkeys, pyow (=P), which is a general alarm call, and hack (=H), which is typically used in the presence of eagles. The putty-nosed monkeys also produce pyow-hack combinations consisting of a number of pyows followed by a number of hacks. While the individual pyows and hacks are alarm calls, the pyow-hack sequences relate to group movement. Using playback experiments, Arnold and Zuberbühler (2006a,b, 2008, 2012, 2013) demonstrated that the overall length of the sequence is statistically related to the distance traveled by the group; the number of pyows and hacks within the equal-length sequences did not affect the distance. Thus, the researchers observed similar behavior when they played back PPPHHH, PIIHHH, and other P-H combinations of the same length.

Schlenker et al. [(2016): 33] point out that the different pyow-hack sequences of the same length are phonologically complex, but lexically simple. They are phonologically complex due to the various numbers of pyows and hacks (see also Mitani and Marler, 1989). The sequences are lexically simple because they are associated with comparable distance traveled, regardless of the number of actual pyows and hacks. How can we capture both the phonological complexity and the lexical simplicity of these sequences? Looking at the different possibilities, there are two compartments, one for pyows, the other for hacks, as shown in Table 1.

Each compartment may contain a varying number of pyows or a varying number of hacks.\(^3\) Crucially, we never find a sequence such as PHP (Arnold and Zuberbühler, 2012), because this sequence would require more than two compartments. On the FSG view of monkey learning behavior, we would predict that PHP is possible, contrary to fact.\(^4\)

Other systems that Miyagawa and Clarke (2019) explore have the same dual-compartment character. The dual-compartment

| Table 1 | Dual-compartment frame (Miyagawa and Clarke, 2019). |
|---------|------------------|
| pyow\(^+\) | hack\(^+\) |
| 1       | 2               |

\(^1\)Studies have attempted to demonstrate that humans are not the only ones capable of mastering grammars above FSG. These include Rey et al. (2012) for baboons, Abe and Watanabe (2011) for Bengalese finches, and Gentner et al. (2006) for starlings. See Fitch (2017) and ten Cate (2017) for critiques. There are other works that have tested whether nonhuman animals are capable of learning non-adjacent dependencies, including Newport and Aslin (2004), Newport et al. (2004), Malassis et al. (2018), and Versace et al. (2019). As Wilson et al. [(2020): 853] conclude, “these studies demonstrate that at least some nonhuman animals appear to be sensitive to these types of nonadjacent dependencies, but also point to potential cross-species differences, including between humans and nonhuman animals, in how they might be learned.”

\(^2\)See Rendall (2021) for critique of recent work on primate semantics and syntax.

\(^3\)Progovac (2015) proposed what she calls a “two-slot mold.” This is similar to our dual-compartment frame, although her proposal is based on speculation about earlier forms of human language.

\(^4\)Most works aiming at eliciting an FSG grammar from nonhuman primates resort to pattern discrimination rather than on the combinatorial complexity of vocal production. There is no known case of vocal production that combines more than two calls, as observed in Miyagawa and Clarke (2019). This binarity recalls the dichotomy between vocal production/vocal perception in nonhuman primates: while the former is highly restricted, the latter is argued to be more sophisticated (Seyfarth and Cheney, 1986, 2003; Fitch and Zuberbühler, 2013). At this point, however, there is no reason to associate a full-fledged FSG to tamarins even in their pattern-discrimination perception.
frame can trivially be modeled by FSG, but it is by no means FSG in the standard sense in that there is no operation of any kind that can potentially lead to strings of infinite length.

**DISCUSSION**

While F&H used the (AB)⁶ stimulus under the assumption that this models FSG, I suggest that what F&H demonstrated for tamarins was that they are capable of learning binary combinations, which occur in natural settings. In fact, F&H [(2004): 379] entertain the possibility that “tamarins fail the PSG because their ability to differentiate successive items is limited to runs of two.” They reject this idea because they tested A-A-B-B along with A-A-A-B-B-B, and tamarins failed to learn both sequences. However, A-A-B-B sequence cannot easily fit into the dual-compartment frame because for each A, there is B. This kind of relation is expressed by a hierarchical structure, as F&H themselves note. This, in turn, casts doubt on applying formal grammar based on the Chomsky hierarchy for distinguishing learning behavior of nonhuman primates from that of humans. The learning behavior of nonhuman primates does not appear susceptible even to the simplest formal grammar (FSG) on the hierarchy.

There is also neuroanatomical evidence for the idea that the (AB)⁵ sequence as used by F&H does not implicate FSG. Friederici et al. (2006) (see also Friederici et al., 2012) demonstrated that the PSG sequence, A⁵B⁵, similar to the stimulus created by F&H, activates Brodmann area 44 of the Broca’s area and the frontal operculum.⁵ In contrast, the “FSG” sequence of (AB)⁶ only recruits the frontal operculum. The frontal operculum is a phylogenetically older part of the brain.

Other studies implicate the left anterior temporal lobe in human language combinatorial/hierarchical operations without mention of Broca’s area and the frontal operculum (Bemis and Pylkkänen, 2011; Brennan and Pylkkänen, 2017).

**REFERENCES**

Abe, K., and Watanabe, D. (2011). Songbirds possess the spontaneous ability to discriminate syntactic rules. *Nat. Neurosci.*, 14, 1067–1074. doi: 10.1038/nn.2869

Amunts, K., Lenzen, M., Friederici, A. D., Schleicher, A., Morosan, P., Palomer-Gallagher, N., et al. (2010). Broca’s region: novel organizational principles and multiple receptor mapping. *PLoS Biol.* 8:e1000489. doi: 10.1371/journal.pbio.1000489

Amunts, K., Schleicher, A., Bürgel, U., Mohlberg, H., Uylings, H. B., and Zilles, K. (1999). Broca’s region revisited: cytoarchitecture and intersubject variability. *J. Comp. Neurol.* 412, 319–341. doi: 10.1002/(SICI)1096-9861(19990920)412:2<319::AID-CNE10>3.0.CO;2-7

Arnold, K., and Zuberbühler, K. (2006a). Language evolution: semantic combinations in primate calls. *Nature* 441, 303–303. doi: 10.1038/441303a

Arnold, K., and Zuberbühler, K. (2006b). The alarm-calling system of adult male putty-nosed monkeys, *Cercopithecus nictitans martini*. *Anim. Behav.* 72, 643–653. doi: 10.1016/j.anbehav.2005.11.017

Arnold, K., and Zuberbühler, K. (2008). Meaningful call combinations in a non-human primate. *Carr. Biol.* 18, R202–R203. doi: 10.1016/j.cub.2008.01.040

Arnold, K., and Zuberbühler, K. (2012). Call combinations in monkeys: compositional or idiomatic expressions? *Brain Lang.* 120, 303–309. doi: 10.1016/j.bandl.2011.10.001

Arnold, K. (2013). Female putty-nosed monkeys use experimentally altered contextual information to disambiguate the cause of male alarm calls. *PLoS ONE.* 8:e65660. doi: 10.1371/journal.pone.0065660

Balari, S., Benitez-Burraco, A., Camps, M., Longa, V. M., Lorenzo, G., and Uriagereka, J. (2011). The archaeological record speaks: Bridging anthropology and linguistics. *Int. J. Dev. Biol.* 11, 1–17. doi: 10.4061/2011/382679

Bemis, D. K., and Pylkkänen, L. (2011). Simple composition: a magnetoencephalography investigation into the comprehension of minimal linguistic phrases. *J. Neurosci.* 31, 2801–2814. doi: 10.1523/JNEUROSCI.5003-10.2011

Brennan, J. R., and Pylkkänen, L. (2017). MEG evidence for incremental sentence composition in the anterior temporal lobe. *Cogn. Sci.* 41, 1515–1531. doi: 10.1111/cogs.12445

Chomsky, N. (1956). Three models for the description of language. *IEEE Trans. Inf. Theory.* 2, 113–124. doi: 10.1109/TIT.1956.105681

Chomsky, N. (1959). On certain formal properties of grammars. *Inf. Control.* 2, 137–167. doi: 10.1016/S0019-9958(59)90362-6

Fitch, W. T. (2017). “Dendrophilia and the Evolution of Syntax,” in *Origins of Human Language: Continuities and Discontinuities with Nonhuman Primates*, eds. I.-J. Boe, J. Fogat, P. Perrier, and J.-L. Schwartz (Bern: Peter Lang), 305–328.

Fitch, W. T., and Hauser, M. D. (2004). Computational constraints on syntactic processing in a nonhuman primate. *Science.* 303, 377–380. doi: 10.1126/science.1089401

Fitch, W. T., and Zuberbühler, K. (2013). “Primate precursors to human language: Beyond discontinuity,” in *Evolution of Emotional Communication: From Sounds in Nonhuman Mammals to Speech and Music in Man*, eds. E. Altenmüller,
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Friederici, A. D., Oberecker, R., and Brauer, J. (2012). Neurophysiological preconditions of syntax acquisition. Psychol. Res. 76, 204–211. doi: 10.1007/s00426-011-0357-0

Longa, V. M. (2013). The evolution of the Faculty of Language from a Chomskyan perspective: Bridging Linguistics and Biology. J Anthropol Sci. 91, 1–48. doi: 10.4436/JASS.91011

Malassis, R., Rey, A., and Fagot, J. (2018). Non-adjacent dependencies processing in human and non-human primates. Cognitive Sci. 42, 1677–1699. doi: 10.1111/cogs.12617

Mitani, J. C., and Marler, P. (2021). Aping language: Historical perspectives on the quest for uniquely human capacity. Oxford: Oxford University Press. doi: 10.1093/acprof:oso/9780198736547.001.0001

Rendall, D. (2021). Aping language: Historical perspectives on the quest for semantics, syntax, and other rarefied properties of human language in the communication of primes and other animals. Front. Psychol. 12:675172. doi: 10.3389/fpsyg.2021.675172

Rey, A., Perruchet, P., and Fagot, J. (2012). Centre-embedded structures are a by-product of associative learning and working memory constraints: Evidence from baboons (Papio Papius). Cognition. 123, 180–184. doi: 10.1016/j.cognition.2011.12.005

Sanides, F. (1962). Die Architektion des Menschlichen Stirnhirns: Zugleich eine Darstellung der Prinzipien Seiner Gestaltung als Spiegel der Stammgeschichtlichen Differenzierung der Grosshirnrinde. Berlin/Heidelberg: Springer-Verlag. Available online at: www.springer.com/de/book/9783540040286 (accessed in September 6, 2021). doi: 10.1007/978-3-642-86210-6

Schlenker, P., Chenla, E., Schel, A. M., Fuller, J., Gautier, J.-P., Kuhn, J., et al. (2016). Formal monkey linguistics. Theor. Linguist. 42, 1–90. doi: 10.1515/tl-2016-0001

Seyfarth, R., Cheney, D., and Marler, P. (1980a). Monkey responses to three different alarm calls: evidence of predator classification and semantic communication. Science. 210, 801–803. doi: 10.1126/science.733999

Seyfarth, R. M., and Cheney, D. L. (1986). Vocal development in vervet monkeys. Anim. Behav. 34, 1640–1658. doi: 10.1016/S0003-3472(86)80252-4

Seyfarth, R. M., and Cheney, D. L. (2003). Signalers and receivers in animal communication. Annu. Rev. Psychol. 54, 145–173. doi: 10.1146/annurev.psych.54.100101.145121

Zaccarella, E., and Friederici, A. D. (2015a). Reflections of word processing in the insular cortex: a sub-regional parcellation based functional assessment. Brain Lang. 142, 1–7. doi: 10.1016/j.bandl.2014.12.006

Zaccarella, E., and Friederici, A. D. (2015b). Merge in the Human Brain: A Sub-Region Based Functional Investigation in the Left Pars Opercularis. Front. Psychol. 6:1818. doi: 10.3389/fpsyg.2015.01818

Zillas, K., and Amunts, K. (2009). Receptor mapping: architecture of the human cerebral cortex. Curr. Opin. Neurol. 22, 331–339. doi: 10.1097/WCO.0b013e32832d95db

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