

PSYCHOLOGICAL SCIENCE

Comment on “Nonadjacent dependency processing in monkeys, apes, and humans”

Jonathan Rawski^{1,2,*†}, William Idsardi^{3,4†}, Jeffrey Heinz^{1,2†}

We comment on the technical interpretation of the study of Watson *et al.* and caution against their conclusion that the behavioral evidence in their experiments points to nonhuman animals' ability to learn syntactic dependencies, because their results are also consistent with the learning of phonological dependencies in human languages.

Watson *et al.* (1) provide some important findings about animal pattern recognition abilities that are relevant to the understanding of human language. However, they perpetuate a common misconception that we aim to correct here: They identify nonadjacent dependencies (Non-ADs) in language systems with a language's syntax. Human languages have separate—but not disjoint—systems governing the combinatorial patterning of sounds within words (phonology) and the combinatorial patterning of words within sentences (syntax), both of which have Non-ADs. Furthermore, mathematical and computational investigations of language reveal that the Non-ADs in syntax are characteristically different—they form a superset of the phonological Non-ADs (see Fig. 1) (2, 3). We therefore advocate a more conservative interpretation of the results of Watson *et al.*

As we examine the language pattern abilities in nonhuman animals (4, 5), it is crucially important that we attend to the combinatorial difference between human phonology and syntax to probe whether the animals are sensitive to strictly syntactic patterns (Y in Fig. 1) as opposed to patterns that are common to both phonology and syntax (X in Fig. 1). The observation that syntactic patterns extend the class found in phonology led to the phonological continuity hypothesis (6): Auditory pattern recognition in nonhuman animals shares important characteristics with human phonology, not human syntax, and therefore, the human capacity for language arose by adding additional cognitive or memory capacity to enable the more expressive syntactic Non-ADs. In this light, the experiments

of Watson *et al.* (7–9) confirm the results of prior experiments: Nonhuman animals can successfully learn phonological patterns and as yet present no unambiguous evidence for syntactic pattern learning.

Common examples of phonological Non-ADs include vowel and consonant harmony (10). For example, Finnish vowels are divided into three kinds: front (y, ö, and ä), back (u, o, and a), and neutral (i and e) (11). Native Finnish words cannot mix front and back vowels, although neutral vowels can freely occur among instances of these harmonizing vowels. As a consequence, we can create vowel-based versions of the A-X-B stimuli of Watson *et al.* by adding “chameleon” suffixes such as *ssa/ssä* (meaning “in”) to stems in Finnish, for example, *Pori-ssa* “in Pori” versus *kyli-ssä* “in the villages” with **o...a** and **y...ä** filling the A and B roles and **i** (and the intervening consonants) filling the role of X. This demonstrates that A-X-B Non-ADs are not a diagnostic for syntactic patterning.

In contrast to the linear, sequence-based Non-ADs in phonology, human syntax crucially involves recursive, nested hierarchical relations (12), and syntactic Non-ADs often rely on the relative scope of the items. A simple case from English is the restriction that words like “anymore” must fall within the scope of a negative item, i.e., “not ... anymore”. The most important question is how humans reach a semantic understanding of the meaning of these sentences S4, but in some cases, the violation of a syntactic Non-AD can reduce to a sentence being either “valid” or “invalid,” that is, having at least one valid interpretation versus none.

- 1) Valid: He is **not** working **anymore**.
- 2) Invalid: He is working **anymore**.

(Although we note that there are some English dialects that have positive “anymore” with a meaning akin to “nowadays” (13) in which sentences like S2 do occur.) In the case of “not,” its scope is the entire predicate (or verb phrase) “working anymore.” However, English also allows sentences to be nested inside sentences, such as sentential modifiers of nouns, and that is where we can see the difference by changing the scope of “not”:

- 3) Valid: The man who is crying is **not** working **anymore**.
- 4) Invalid: The man who is **not** crying is working **anymore**.

As shown in the parse trees in Fig. 2, the scope of “not” in S4 is “crying” and “anymore” occurs outside its scope, violating the syntactic scopal Non-AD between “not” and “anymore.”

One potential explanation for the hierarchical Non-ADs in syntax is that they are tied up with the meaning of sentences, which is an explanation consistent with the absence of meaning for individual sounds within a phonological word. However, such an explanation is not consistent with experimental results, which show that

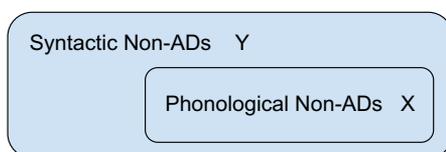


Fig. 1. Non-ADs in human language. Experiments testing Non-ADs in animals examine patterns of type X. This brief commentary points out that to establish that animals can learn human-like syntactic dependencies, experiments need to find a way to test Non-ADs of type Y.

¹Linguistics Department, Stony Brook University, Stony Brook, NY 11794, USA. ²Institute for Advanced Computational Science, Stony Brook University, Stony Brook, NY 11794, USA. ³Neuroscience and Cognitive Science Program, University of Maryland, College Park, MD 20742, USA. ⁴Linguistics Department, University of Maryland, 1401 Marie Mount Hall, College Park, MD 20742, USA. *Corresponding author. Email: jonathan.rawski@stonybrook.edu †These authors contributed equally to this work.

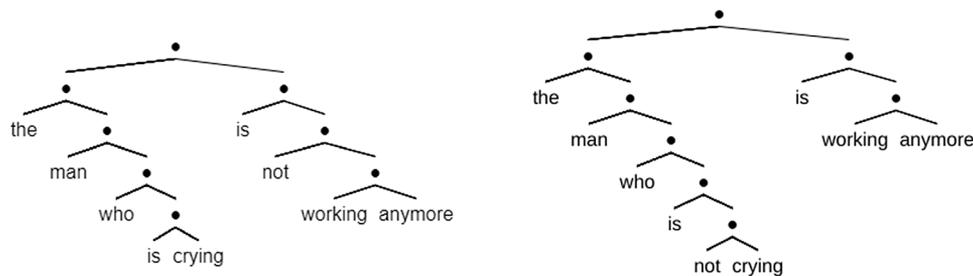


Fig. 2. Scope in syntactic structures. Words like “anymore” need to be within the scope of “not” to receive the intended interpretation. This nonadjacent dependency is satisfied in the left parse tree, where the scope of “not” is “working anymore,” but not in the right parse tree, where the scope of “not” is “crying.”

meaningless “jabberwocky” speech is processed in the same way as naturally meaningful speech (14, 15).

Animal pattern learning experiments across species examine Non-ADs consistent with human phonology (1, 4–6). To accurately probe whether nonhuman animals have the capability to discriminate Non-ADs consistent with human syntax, the right experimental contrasts must be drawn, such as those involving hierarchical relations like scope. A robust experimental design showing that animals can learn these strictly syntactic Non-ADs would directly challenge the phonological continuity hypothesis and, perhaps, provide evidence for the evolutionary primacy of syntax over phonology (16). We appreciate how hard it is to design effective experiments with animals and agree that it is very important to continue this line of research. However, it is also important for us as a field to acknowledge the challenges and limitations of these experiments when comparing the results with human language patterns. We advocate closer dialog and collaboration between language scientists, cognitive scientists, and computer scientists to design experiments with the appropriate contrasts to ensure experimental inferences about comparative cognition are theoretically sound and analytically robust (17).

REFERENCES AND NOTES

1. S. K. Watson, J. M. Burkart, S. J. Schapiro, S. P. Lambeth, J. L. Mueller, S. W. Townsend, Nonadjacent dependency processing in monkeys, apes, and humans. *Sci. Adv.* **6**, eabb0725 (2020).
2. J. Heinz, W. J. Idsardi, Sentence and word complexity. *Science* **333**, 295–297 (2011).
3. J. Heinz, W. J. Idsardi, What complexity differences reveal about domains in language. *Top. Cogn. Sci.* **5**, 111–131 (2013).
4. W. T. Fitch, A. D. Friederici, P. Hagoort, Pattern perception and computational complexity: Introduction to the special issue. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **367**, 1925–1932 (2012).

5. G. Jäger, J. Rogers, Formal language theory: Refining the Chomsky hierarchy. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **367**, 1956–1970 (2012).
6. W. T. Fitch, What animals can teach us about human language: The phonological continuity hypothesis. *Curr. Opin. Behav. Sci.* **21**, 68–75 (2018).
7. G. J. L. Beckers, J. J. Bolhuis, K. Okanoya, R. C. Berwick, Birdsong neurolinguistics: Songbird context-free grammar claim is premature. *Neuroreport* **23**, 139–145 (2012).
8. R. C. Berwick, N. Chomsky, *Why Only Us?* (MIT Press, 2016).
9. B. Samuels, Can a bird brain do phonology? *Front. Psychol.* **6**, 1082 (2015).
10. S. Rose, R. Walker, Harmony systems, in *The Handbook of Phonological Theory*, J. Goldsmith, J. Riggle, A. C. L. Yu, Eds. (Blackwell, 2011), pp. 240–290.
11. F. Karlsson, *Finnish: A Comprehensive Grammar* (Routledge, 2018).
12. N. Chomsky, *Syntactic Structures* (Mouton, 1957).
13. K. Malone, Any more in the affirmative. *Am. Speech* **6**, 460 (1931).
14. C. Pallier, A.-D. Devauchelle, S. Dehaene, Cortical representation of the constituent structure of sentences. *Proc. Natl. Acad. Sci. U.S.A.* **108**, 2522–2527 (2011).
15. W. Matchin, C. Brodbeck, C. Hammerly, E. Lau, The temporal dynamics of structure and content in sentence comprehension: Evidence from fMRI-constrained MEG. *Hum. Brain Mapp.* **40**, 663–678 (2019).
16. K. Collier, B. Bickel, C. P. van Schaik, M. B. Manser, S. W. Townsend, Language evolution: Syntax before phonology? *Proc. Biol. Sci.* **281**, 1788 (2014).
17. I. van Rooij, G. Baggio, Theory before the test: How to build high-verisimilitude explanatory theories in psychological science. *Perspect. Psychol. Sci.* **2020**, 1745691620970604 (2020).

Acknowledgments

Funding: The authors declare that they have no funding sources. **Author contributions:** All authors contributed equally to this paper. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** All data needed to evaluate the conclusions in the paper are present in the paper.

Submitted 7 December 2020

Accepted 17 May 2021

Published 21 July 2021

10.1126/sciadv.abg0455

Citation: J. Rawski, W. Idsardi, J. Heinz, Comment on “Nonadjacent dependency processing in monkeys, apes, and humans”. *Sci. Adv.* **7**, eabg0455 (2021).

Comment on "Nonadjacent dependency processing in monkeys, apes, and humans"

Jonathan Rawski, William Idsardi and Jeffrey Heinz

Sci Adv 7 (30), eabg0455.
DOI: 10.1126/sciadv.abg0455

ARTICLE TOOLS <http://advances.sciencemag.org/content/7/30/eabg0455>

RELATED CONTENT <http://advances.sciencemag.org/content/advances/7/30/eabj1517.full>
<http://advances.sciencemag.org/content/advances/6/43/eabb0725.full>

REFERENCES This article cites 13 articles, 3 of which you can access for free
<http://advances.sciencemag.org/content/7/30/eabg0455#BIBL>

PERMISSIONS <http://www.sciencemag.org/help/reprints-and-permissions>

Use of this article is subject to the [Terms of Service](#)

Science Advances (ISSN 2375-2548) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005. The title *Science Advances* is a registered trademark of AAAS.

Copyright © 2021 The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original U.S. Government Works. Distributed under a Creative Commons Attribution NonCommercial License 4.0 (CC BY-NC).