PSYCHOLOGICAL SCIENCE

Reply to comment on "Nonadjacent dependency processing in monkeys, apes, and humans"

Stuart K. Watson[1,2]*, Judith M. Burkart[3], Steven J. Schapiro[4,5], Susan P. Lambeth[4], Jutta L. Mueller[6†], Simon W. Townsend[1,2,7†]

Rawski *et al.* revisit our recent findings suggesting the latent ability to process nonadjacent dependencies ("Non-ADs") in monkeys and apes. Specifically, the authors question the relevance of our findings for the evolution of human syntax. We argue that (i) these conclusions hinge upon an assumption that language processing is necessarily hierarchical, which remains an open question, and (ii) our goal was to probe the foundational cognitive mechanisms facilitating the processing of syntactic Non-ADs—namely, the ability to recognize predictive relationships in the input.

Rawski *et al.* (this issue) revisit our recent findings regarding adjacent and nonadjacent dependency (Non-AD) processing in marmosets and chimpanzees (*1*). Specifically, they take issue with our interpretation that such experiments are able to shed light on the cognitive building blocks underpinning human syntax. The crux of their argument relies on the assumption that human syntax (and, by extension, syntactic Non-ADs) necessarily involves "recursive, nested hierarchical relations", which are absent from the artificial grammars presented in our experiment. Without denying the general importance of investigating the processing of nested, hierarchical structures in human and nonhuman cognition, we disagree with the idea that there is only one road to uncovering the evolutionary precursors to human syntax.

Whether humans obligatorily represent and process language hierarchically remains an open, empirical question. Language can be equally analyzed nonhierarchically rather invoking more linear-based sequential mechanisms (*2*–*4*). Since we remain agnostic on this issue, the purpose of our study was to determine whether apes and monkeys are capable of tracking predictive relationships between nonadjacent auditory stimuli, a necessary precondition for syntax regardless of the presence of hierarchy. Processing Non-ADs in hierarchical syntax would be impossible without this basic sensitivity to sequential input (*5*). We do not contest that this capacity is also fundamental to the production and processing of phonological Non-ADs but disagree that our findings are more demonstrative of phonological as opposed to syntactic-pattern learning, because tracking predictive relationships in the input is necessary for both.

Examining whether nonhuman animals are capable of processing more hierarchical, recursive structures as advocated by Rawski *et al.* is an extremely interesting topic. However, this is a different research program to that set about by Watson *et al.* (*1*), which rather takes a more "bottom-up" approach of examining the core capacities that are likely to scaffold the "higher" faculties related to hierarchical processing. These approaches are, of course, complimentary: Specifically, we argue that establishing this core capacity of auditory Non-AD processing, which had never been demonstrated before in chimpanzees, is a logical foundation toward probing the more complex, hierarchical structures that Rawski *et al.* are interested in. Having now established such a capacity, we anticipate that future research will expand in the direction suggested by Rawski *et al.* and determine the absolute limits of dependency processing in our primate cousins—thereby, perhaps, discovering where exactly the cognitive Rubicon separating language-ready minds from those of animals lies (*6*).

Our study might still be several steps away from that Rubicon, and primates may even share more complex computational capacities involved in syntax than those that were tested by our study. Yet, we hold that this does not mean that the ability that we demonstrated is irrelevant as an evolutionary precursor of syntax. One might draw an analogy to a different research field to illustrate our point. In language acquisition research, it has been shown that, from early on, infants are sensitive to syntactic categories (*7*, *8*) and relations (*9*, *10*), yet syntactic development is ongoing until early adolescence [see Skeide and Friederici (*11*) for review]. More precisely, early competence in infants' processing of structural properties of language may often be strongly based on scaffolding by acoustic properties of the items that have to be related to each other and, thus, be surface-based rather than abstract and syntactic (*12*). Eventually, though, relations that are based on surface properties develop into relations that are more abstract and categorical in nature in children's development (*13*). It would therefore be inappropriate to completely dismiss the earlier stages of development as irrelevant to syntactic emergence on the basis that they do not encompass the same level of complexity and abstraction as later stages of development. Rather, it makes sense to see them as important steps toward syntax, as is done by various bootstrapping approaches (*14*). Analogously, we regard the capacity for learning Non-ADs that we observed in our primate relatives as equally relevant first steps toward the evolution of human syntax. In short, we argue that a plurality of complimentary research programs is likely to be more productive in shedding light on the evolution of syntax than a singular focus on hierarchy.

[1]Department of Comparative Language Science, University of Zurich, Zurich, Switzerland. [2]Center for the Interdisciplinary Study of Language Evolution, Zurich, Switzerland. [3]Anthropological Institute and Museum, University of Zurich, Zurich, Switzerland. [4]UT MD Anderson Cancer Research Center, Bastrop, TX, USA. [5]Department of Experimental Medicine, University of Copenhagen, Copenhagen, Denmark. [6]Institute of Linguistics, University of Vienna, Vienna, Austria. [7]Department of Psychology, University of Warwick, Coventry, UK.
*Corresponding author. Email: swatso88@gmail.com
†These authors contributed equally to this work as joint last authors.

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. S. L. Frank, R. Bod, M. H. Christiansen, How hierarchical is language use? *Proc. R. Soc. B Biol. Sci.* **279**, 4522–4531 (2012).
3. S. L. Frank, T. Trompenaars, S. Vasishth, Cross-linguistic differences in processing double-embedded relative clauses: Working-memory constraints or language statistics? *Cognit. Sci.* **40**, 554–578 (2016).
4. S. L. Frank, M. H. Christiansen, Hierarchical and sequential processing of language. *Lang. Cognit. Neurosci.* **33**, 1213–1218 (2018).
5. J. Uddén, M. de Jesus Dias Martins, W. Zuidema, W. T. Fitch, Hierarchical structure in sequence processing: How to measure it and determine its neural implementation. *Top. Cogn. Sci.* **12**, 910–924 (2020).
6. M. C. Corballis, Crossing the Rubicon: Behaviorism, language, and evolutionary continuity. *Front. Psychol.* **11**, 653 (2020).
7. R. Shi, J. F. Werker, J. L. Morgan, Newborn infants' sensitivity to perceptual cues to lexical and grammatical words. *Cognition* **72**, B11–B21 (1999).
8. B. Höhle, J. Weissenborn, German-learning infants' ability to detect unstressed closed-class elements in continuous speech. *Dev. Sci.* **6**, 122–127 (2003).
9. L. M. Santelmann, P. W. Jusczyk, Sensitivity to discontinuous dependencies in language learners: evidence for limitations in processing space. *Cognition* **69**, 105–134 (1998).
10. B. Höhle, M. Schmitz, L. M. Santelmann, J. Weissenborn, The recognition of discontinuous verbal dependencies by German 19-month-olds: Evidence for lexical and structural influences on children's early processing capacities. *Lang. Learn. Dev.* **2**, 277–300 (2006).
11. M. A. Skeide, A. D. Friederici, The ontogeny of the cortical language network. *Nat. Rev. Neurosci.* **17**, 323–332 (2016).
12. J. L. Mueller, C. ten Cate, J. M. Toro, A comparative perspective on the role of acoustic cues in detecting language structure. *Top. Cogn. Sci.* **12**, 859–874 (2020).
13. J. Culbertson, E. Koulaguina, N. Gonzalez-Gomez, G. Legendre, T. Nazzi, Developing knowledge of nonadjacent dependencies. *Dev. Psychol.* **52**, 2174–2183 (2016).
14. B. Höhle, R. Bijeljac-Babic, B. Herold, J. Weissenborn, T. Nazzi, Language specific prosodic preferences during the first half year of life: Evidence from German and French infants. *Infant Behav. Dev.* **32**, 262–274 (2009).

Acknowledgments: We are grateful to J. Scwab, A. Bosshard, M. Rüdisühli, and A. Hervais-Adelman for feedback on this manuscript. **Funding:** Funding was provided by the Swiss National Science Foundation (PP00P3_163850 to SWT) and NCCR Evolving Language (agreement no.51NF40_180888). **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** There are no data associated with this paper.

Submitted 23 April 2021
Accepted 8 June 2021
Published 21 July 2021
10.1126/sciadv.abj1517

Citation: S. K. Watson, J. M. Burkart, S. J. Schapiro, S. P. Lambeth, J. L. Mueller, S. W. Townsend, Reply to comment on "Nonadjacent dependency processing in monkeys, apes, and humans". *Sci. Adv.* **7**, eabj1517 (2021).