BABBLING BEHAVIOR: SHARED VOCAL ONTOGENETIC FEATURES IN BAT PUPS AND HUMAN INFANTS

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Speech is the vocal motor output aspect of language and requires precise control over a complex muscle system (e.g. laryngeal and orofacial muscles) steered by neuronal mechanisms. During ontogeny, every child is challenged with the acquisition of speech sounds. The first utterances resembling speech sounds are observed during babbling, a distinctive vocal behavior in human infants (Oller, 2000). Babbling is a production milestone in infant speech development because it enables infants to practice speech sounds by gaining control over their speech articulators (Oller, 2000; ter Haar et al., 2021; Vihman, 2014).

With our study, we introduce a new and promising mammalian candidate for comparative biolinguistic research on vocal ontogenetic processes, the greater sac-winged bat *Saccopteryx bilineata*. The bat *S. bilineata* is a vocal production learner (Knörnschild, Nagy, Metz, Mayer, & von Helversen, 2010) and exhibits a conspicuous vocal practice phase during ontogeny (Fernandez, Burchardt, Nagy, & Knörnschild, 2021; Knörnschild, Behr, & von Helversen, 2006). This pup vocal practice is strongly reminiscent of infant babbling: it is organized in bouts composed of multisyllabic repetitive sequences that are interspersed by short silent intervals. Babbling bouts can last up to 43 minutes and throughout the babbling phase (i.e. the period between first and last day of babbling), pups spend about 30% of their active time with babbling. During babbling pups learn to produce song by imitating adult tutors; pups' renditions of adult song are often found in babbling bouts (Fernandez et al., 2021; Knörnschild et al., 2006; Knörnschild et al., 2010).

In human infants, irrespective of the language to be learned, babbling is characterized by several common features, e.g. repetitiveness, rhythmicity, early

onset in infancy (Oller, 2000; Vihman, 2014). Our study investigated whether babbling behavior in *S. bilineata*, pups is characterized by the same features that define infant babbling. The aim was to provide the first formal comparison of babbling features across vocal learning mammals.

For this study, we investigated the entire vocal ontogeny of 20 pups from two wild populations in Costa Rica and Panama. Pup babbling was organized in three hierarchical levels: the syllables (level 1) were concatenated to sequences called syllable trains (level 2), which – interspaced by silent intervals – constituted the babbling bouts (level 3). On the syllable level, we investigated the following features: age at babbling onset (A), babbling bout composition (B), syllable type acquisition (C), syllable type emergence during the babbling phase (D), reduplication (E), social context and function of babbling (G) and universality (H). We analyzed at least one babbling bout per week and pup (N=216 babbling bouts) for investigating all parameters, except for reduplication (E). To investigate (E) we classified 55´056 syllables of 10 pups into syllable types and calculated a correlation matrix showing the observed repetition rates of the syllable types present in babbling. Rhythmicity (F) was investigated on the syllable train level (N=30 trains, 712 syllables) by measuring syllable inter-onset intervals and further assessed with a normalized pairwise variability index. For (A-D) and (H) we visually classified syllable types in babbling bouts based on their high spectro-temporal similarity with the adult vocal repertoire (which is entirely delineated). Our visual classification was statistically verified by measuring a subset of our data and performing discriminant function analyses (acoustic analysis: Avisoft SasLab Pro, DFA: SPSS).

Our results revealed that the features that define human infant babbling are also characteristic of pup babbling: (A) babbling onset occurred early, at one third of the entire vocal ontogeny, (B) babbling bouts were composed of adult-like syllable types (comparable to infant canonical syllables) and undifferentiated proto-syllables (comparable to infant speech precursors). Pups only acquired a subset of the adult syllable type repertoire (C) and adult syllable type acquisition followed a non-linear pattern (D). Bouts were dominated by reduplication of syllable types (E) and included syllable trains with regular beats (F). Babbling did not require a social context for production and the adult-like syllable types did not elicit the same reactions that they would when produced by adult bats (G). All pups – irrespective of sex and regional origin – engaged in babbling behavior (and showed no significant differences concerning the babbling features).

In conclusion, our study demonstrated that the babbling behavior of *S. bilineata* pups is characterized by the same features that define infant babbling (Fernandez et al., 2021).

The similarities in babbling features between two species with common traits such as VPL, laryngeal sound production and similar brain architecture, are a promising basis for comparative investigations of neuronal substrates in mammalian VPL (Jarvis, 2019).

References

Fernandez, A. A., Burchardt, L. S., Nagy, M., & Knörnschild, M. (2021). Babbling in a vocal learning bat resembles human infant babbling. *Science, 373*(6557), 923-926. doi:10.1126/science.abf9279

Jarvis, E. D. (2019). Evolution of vocal learning and spoken language. *Science, 366*(6461), 50-54. doi:10.1126/science.aax0287

Knörnschild, M., Behr, O., & von Helversen, O. (2006). Babbling behavior in the sac-winged bat (*Saccopteryx bilineata*). *Naturwissenschaften, 93*(9), 451-454. doi:10.1007/s00114-006-0127-9

Knörnschild, M., Nagy, M., Metz, M., Mayer, F., & von Helversen, O. (2010). Complex vocal imitation during ontogeny in a bat. *Biology Letters, 6*(2), 156-159. doi:10.1098/rsbl.2009.0685

Oller, D. K. (2000). *The Emergence of the Speech Capacity*: Mahwah, NJ, Lawrence Erlbaum Associates, Inc.

ter Haar, S. M., Fernandez, A. A., Gratier, M., Knörnschild, M., Levelt, C., Moore, R. K., . . . Oller, D. K. (2021). Cross-species parallels in babbling: animals and algorithms. *Philosophical Transactions of the Royal Society B: Biological Sciences, 376*(1836), 20200239. doi:10.1098/rstb.2020.0239

Vihman, M. M. (2014). *Phonological development: The first two years* (2 ed.): John Wiley and Sons, Inc.