IMPACT OF AUDITORY FEEDBACK ON BAT VOCAL DEVELOPMENT

ELLA Z. LATTENKAMP[1,2,*], MEIKE LINNENSCHMIDT[1], EVA MARDUS[1], SONJA C. VERNES[2], LUTZ WIEGREBE[1], MICHAEL SCHUTTE[1]

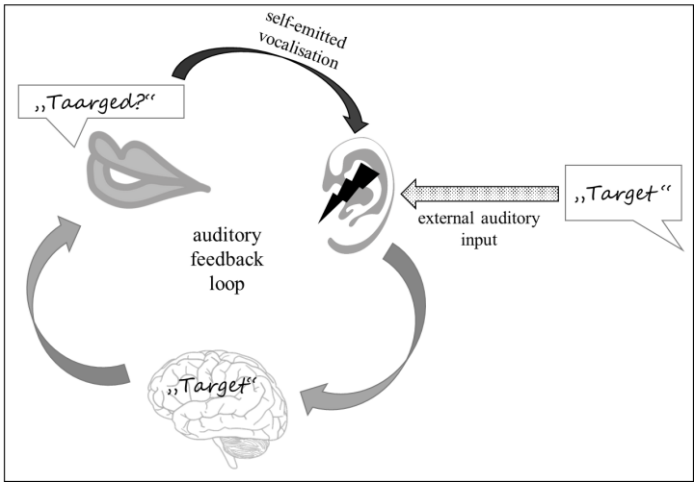
[*]Corresponding author: ella.lattenkamp@evobio.eu
[1]AG Wiegrebe, Dept. Biology II, Ludwig-Maximilians University, Munich, Germany.
[2]Neurogenetics of Vocal Communication Group, Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands.

Speech acquisition in humans is based (1) on the perception of an external auditory target (e.g. adult vocalisations), and (2) the gradual modification of self-emitted vocalisations to match this acoustic target (figure 1) (Kuhl & Meltzoff, 1996). When hearing is severely impaired and auditory feedback is lacking (e.g. in deaf infants), normal adult vocalisations cannot be acquired (Oller & Eilers, 1988). Instead, the vocal development of deaf infants shows variations such as reduced inventories for consonants, vowels and syllables, reduced articulation space, and atypical temporal and coordinative sound production (Hudgins & Numbers, 1942; Brannon, 1966; Clement & Koopmans-van Beinum, 1995; VanDam *et al.*, 2015). Although speech and spoken language acquisition are uniquely human traits, the disrupting effect of lacking auditory feedback is not as rare in the animal kingdom. All species that are capable of vocal learning, i.e. able to acquire novel vocalisations through auditory input, should be impacted by a disruption of sensory input or auditory feedback (figure 1). Significant variations of normal adult vocalisations are expected to occur in any vocal learning species that is deprived of auditory feedback during development (as has been shown in songbirds (e.g. Konishi, 1965; Konishi, 2004)).

Bats have been highlighted as promising mammalian model organisms for the study of vocal learning (Knörnschild, 2014; Vernes & Wilkinson, 2019). Especially for the pale spear-nosed bat, *Phyllostomus discolor*, several indications of vocal learning have previously been published (Esser & Schmidt, 1989; Esser, 1994). Moreover, adult *P. discolor* have been shown to possess a rich vocal repertoire (Lattenkamp *et al.*, 2019) and to be flexible in the spectro-temporal domain of their vocalisations (Lattenkamp *et al.*, 2018). In order to provide further evidence for the vocal learning capacity of *P. discolor*, we investigated the impact

of auditory input and feedback on their vocal development. Complementing previous isolation studies in this species (i.e. exclusive disruption of external auditory input), which focused on the effects on a single vocalisation type (Esser, 1994), we have now investigated the effect of deafening (i.e. disruption of auditory input and feedback) on their full vocal repertoire. Comparisons between the vocalisations of severely hearing-impaired and normal-hearing pups and adult bats allow us to assess the impact of auditory feedback on the vocal development of this species. The hearing impairment led to a significant increase in vocal activity and call amplitude as well as an increase in several other spectro-temporal call parameters. These results present an important contribution to the discussion of the status of *P. discolor* as a vocal learner and the role of this species for the study of vocal learning. This work serves as a basis for further research using the pale spear-nosed bat as a mammalian animal model for vocal learning and contributes to comparative studies on hearing impairment across species.

Figure 1. Schematic of an auditory feedback loop underlying speech acquisition and vocal learning.



In a functional auditory feedback loop the auditory target, e.g. an adult vocalisation (dotted arrow), is perceived and memorised. The self-emitted vocalisation of the target sound is then perceived again (black arrow) and compared to the memorised target. While isolation studies solely prevent the perception of external auditory targets, the disruption of the auditory feedback loop by deafening (black lightning symbol) also disrupts the perception of self-emitted vocalisations and thus the possibility for adjustment towards an internal target.

Acknowledgements

This work was funded by a Human Frontiers Science Program (HFSP) Research grant (RGP0058/2016) awarded to L.W. and S.C.V. The authors want to thank Stephanie Shields and the LMU workshop for help with constructing parts of the setup used in this study and Sabrina Schenk for her excellent bat care.

References

Brannon, J. (1966). The speech production and spoken language of the deaf. *Language and Speech*, 9, 127-36.

Clement, C. J., & Koopmans-van Beinum, F. J. (1995). Influence of lack of auditory feedback: vocalizations of deaf and hearing infants compared. *IFA Proceedings 19*, 25-37.

Esser, K.-H. (1994). Audio-vocal learning in a non-human mammal: the lesser spear-nosed bat *Phyllostomus discolor*. *Neuroreport*, 5: 1718-20.

Esser, K.-H., & Schmidt, U. (1989). Mother-infant communication in the lesser spear-nosed bat *Phyllostomus discolor* (Chiroptera, phyllostomidae): Evidence for acoustic learning. *Ethology*, 82(2), 156-168.

Hudgins, C. V., & Numbers, F. C. (1942). An investigation of the intelligibility of the speech of the deaf. *Genetic Psychology Monographs*, 25, 289-392.

Knörnschild, M. (2014). Vocal production learning in bats. *Current Opinion in Neurobiology*, 28, 80-85.

Konishi, M. (1965). The role of auditory feedback in the control of vocalization in the white-crowned sparrow. *Zeitschrift für Tierpsychologie*, 22, 770-83.

Konishi, M. (2004). The role of auditory feedback in birdsong. *Annals of the New York Academy of Sciences*, 1016, 463-75.

Kuhl, P. K., & Meltzoff, A. N. (1996). Infant vocalizations in response to speech: vocal imitation and developmental change. *Journal of the Acoustical Society of America*, 100, 2425–2438.

Lattenkamp, E. Z., Vernes, S. C., Wiegrebe, L. (2018). Volitional control of social vocalisations and vocal usage learning in bats. *Journal of Experimental Biology*, 211, jeb180729.

Lattenkamp, E. Z., Shields, S. M., Schutte, M., Richter, J., Linnenschmidt, M., Vernes, S. C., Wiegrebe, L. (2019). The vocal repertoire of pale spear-nosed bats in a social roosting context. *Frontiers in Ecology and Evolution*, 7, 16.

Oller, K. D., & Eilers, R. E. (1988). The role of audition in infant babbling. *Child Development*, 59(2), 441-449.

VanDam, M., Oller, K., Ambrose, S. E., Gray, S., Richards, J. A., Xu, D., Gilkerson, J., Silbert, N. H., & Moeller, M. P. (2015). Automated vocal analysis of children with hearing loss and their typical and atypical peers. *Ear Hear*, 36, e146-52.

Vernes, S. C., & Wilkinson, G. S. (2019). Behaviour, biology, and evolution of vocal learning in bats. *Philosophical Transactions of the Royal Society of London, Series B*, 1–31.