NONLINEAR BIASES IN ARTICULATION CONSTRAIN THE DESIGN SPACE OF LANGUAGE

RICK JANSSEN[1], BODO WINTER[2], SEÁN ROBERTS[1],
SCOTT R. MOISIK[1], DAN DEDIU[1]

[1]*Max Planck Institute for Psycholinguistics,*
Nijmegen, the Netherlands
rick.janssen@mpi.nl, sean.roberts@mpi.nl, scott.moisik@mpi.nl, dan.dediu@mpi.nl

[2]*Cognitive & Information Sciences,University of California, Merced,*
California, United States of America
bodo@bodowinter.com

In Iterated Learning (IL) experiments, a participant's learned output serves as the next participant's learning input (Kirby et al., 2014). IL can be used to model cultural transmission and has indicated that weak biases can be amplified through repeated cultural transmission (Kirby et al., 2007). So, for example, structural language properties can emerge over time because languages come to reflect the cognitive constraints in the individuals that learn and produce the language. Similarly, we propose that languages may also reflect certain *anatomical* biases. Do sound systems adapt to the affordances of the articulation space induced by the vocal tract?

The human vocal tract has inherent nonlinearities which might derive from acoustics and aerodynamics (cf. quantal theory, see Stevens, 1989) or biomechanics (cf. Gick & Moisik, 2015). For instance, moving the tongue anteriorly along the hard palate to produce a fricative does not result in large changes in acoustics in most cases, but for a small range there is an abrupt change from a perceived palato-alveolar [ʃ] to alveolar [s] sound (Perkell, 2012). Nonlinearities such as these might bias all human speakers to converge on a very limited set of phonetic categories, and might even be a basis for combinatoriality or phonemic 'universals'.

While IL typically uses discrete symbols, Verhoef et al. (2014) have used slide whistles to produce a continuous signal. We conducted an IL experiment with human subjects who communicated using a software-implemented slide whistle for which the degree of nonlinearity is controlled. A single parameter (α) changes the mapping from slide whistle position (the 'articulator') to the acoustics. With α=0, the position of the slide whistle maps Bark-linearly to the acoustics. As α approaches 1, the mapping gets more double-sigmoidal, creating

three plateaus where large ranges of positions map to similar frequencies. In more abstract terms, α represents the strength of a nonlinear (anatomical) bias in the vocal tract.

Six chains (138 participants) of dyads were tested, each chain with a different, fixed α. Participants had to communicate four meanings (pictographs showing different animals) by producing a continuous signal using the slide-whistle in a 'director-matcher' game, alternating roles (cf. Garrod et al., 2007).

Results show that for high αs, subjects quickly converged on the plateaus. This quick convergence is indicative of a strong bias, repelling subjects away from unstable regions already within-subject. Furthermore, high αs lead to the emergence of signals that oscillate between two (out of three) plateaus. Because the sigmoidal spaces are spatially constrained, participants increasingly used the sequential/temporal dimension with higher αs (i.e., more nonlinear mappings). As a result of this, the average duration of signals with high α was ~100ms longer than with low α. These oscillations could be an expression of a basis for phonemic combinatoriality.

We have shown that it is possible to manipulate the magnitude of an articulator-induced non-linear bias in a slide whistle IL framework. The results show that language might indeed come to reflect the nonlinear mapping from the articulators to acoustics. In particular, the signaling systems in our study quickly converged (within-subject) on the use of stable regions. While these conclusions were drawn from experiments using slide whistles with a relatively strong bias, weaker biases could possibly be amplified over time by repeated cultural transmission, and likely lead to similar outcomes.

Future studies could investigate anatomical biasing with more realistic models of the articulators, and address the interaction with other factors (socio-linguistics, environment, etc.). Our model is a deliberate abstraction from reality in order to tightly control experimental conditions. In reality of course, anatomical biases have to be thought of as one factor that shapes human language, but in complex ways.

References

Garrod S., Fay N., Lee J., Oberlander J., MacLeod T. (2007) Foundations of representation: where might graphical symbol systems come from? *Cognitive Science*, 31, 961-987.

Gick, B., & Moisik, S. R. (2015). Quantal biomechanics in an embodied phonetics. *JASA*, 137(4), 2301–2301.

Kirby, S., Dowman, M., & Griffiths, T. L. (2007). Innateness and culture in the evolution of language. *PNAS, 104*, 5241-5245.

Kirby, S., Griffiths, T.L., & Smith, K. (2014). Iterated learning and the evolution of language. *Current Opinion in Neurobiology*, *28*, 108-114.

Perkell, J. S. (2012). Movement goals and feedback and feedforward control mechanisms in speech production. *J. Neuroling.*, 25(5), 382–407.

Stevens, K. N. (1989). On the quantal nature of speech. *J. Phon.*, *17*, 3-46.

Verhoef, T., Kirby, S., & de Boer, B. (2014). Emergence of combinatorial structure and economy through iterated learning with continuous acoustic signals. *Journal of Phonetics*, *43*, 57-68.