Trade-offs between iconicity and structure in the evolution of combinatorial phonology

Matthias Hofer, Josh Tenenbaum & Roger Levy (Massachusetts Institute of Technology)
mhofer@mit.edu

One design feature of human language is its combinatorial phonology, which allows the formation of an unbounded set of meaningful utterances from a small, finite set of meaningless building blocks. Recent laboratory experiments using artificial languages suggest how such combinatorial building blocks could have evolved culturally from unstructured, continuous signals (e.g., Verhoef, Kirby, de Boer 2014; del Giudice, 2012), but combinatorial structure appears to be in conflict with another property salient in the evolution of language: iconicity. While the building blocks of a combinatorial system should be small, lack independent meaning, and be easy to reproduce, iconic signals don't have those restrictions and are instead motivated by what they refer to. Goldin-Meadow and McNeill (1999) have, moreover, suggested that combinatoriality won't be adopted for the benefits it provides, but to compensate when iconicity is not widely available. This account is intuitively consistent with the observed differences between sign and spoken languages and with recent laboratory work showing that combinatorial structure develops more slowly when iconic mappings between signals and referents are possible (Verhoef, Kirby, de Boer 2016; Little et al, 2017; Roberts, Lewandowski and Galantucci, 2015). However, because these studies primarily assess the effects of iconicity on combinatorial structure indirectly, more specific claims about the evolution of signal structure, such as whether combinatorial signals are only adopted once iconicity is lost, as suggested by Goldin-Meadow and McNeill (1999), are hard to test. Motivated by these questions, we investigate the emergence of a form of iconicity that is more limited in scope yet allows for a more direct quantitative assessment of structure. In particular, we examine the degree to which signals evolve to match the conceptual complexity of their referents when this association is initially at chance (Lewis and Frank, 2016).

Methods. To investigate how iconicity emerges and interacts with the existence of combinatorial structure in language, we conducted an online iterated learning experiment where participants produced auditory signals using a virtual slide whistle instrument (Verhoef et al 2014). Using an iterated learning paradigm allowed us to better isolate contributions from cognitive biases for iconicity and structure from pressures stemming from communicative demands. Participants were split into 15 different learning chains and were instructed to learn an artificial language consisting of eight novel visual objects paired with the whistled signals produced by the participant before them (Figure 1). Subjects engaged in five learning blocks where signals-referent pairings were presented in random order and had to eventually reproduce the eight signals from memory.

Results. Besides replicating the emergence of combinatorial structure (Figure 2A), our main finding is that iconicity emerges in the first generation ($t=2.6$, $p<0.01$; p adjusted for multiple comparisons) but is gradually lost over successive generations (Figure 2B). This is despite the existence of strong synchronic iconicity biases, as revealed in a guessing game, in which participants reliably picked complexity-matching referents for each signal. To analyze how changes in iconicity over generations relate to combinatoriality, we describe the transitions from particular languages from one generation to the next in a vector field model (Figure 3). Consistent with the account above, we find that pronounced levels of iconicity only exist when languages are still relatively unstructured. Combinatorial structure, however, already begins to develop well before these earlier forms of iconicity are lost, suggesting the continued influence of biases for combinatoriality throughout signal evolution. We discuss implications of our findings for different hypotheses about the interaction of pressures for iconicity and structure in language evolution and outline ways of quantifying the underlying cognitive biases in future work using computational models.

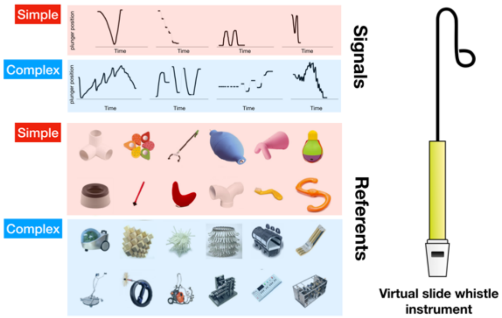
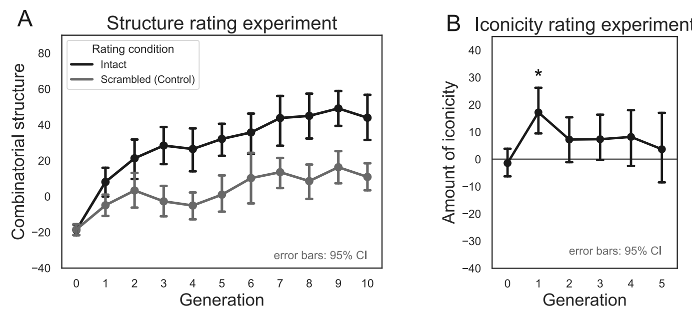


Figure 1 (Left). Signals (collected in a pilot experiment) and referents (from Lewis and Frank, 2016) used in the study. Across chains, the same eight initial signals were randomly paired with referents to keep complexity associations at chance. The virtual slide whistle instrument was controlled with the mouse (pitch) and the space bar (note on/off).

Figure 2 (Right). (A) Combinatorial structure by generation B: Iconicity: measured via auditory complexity of signals associated with simple vs complex referents and absolute difference (right plot)



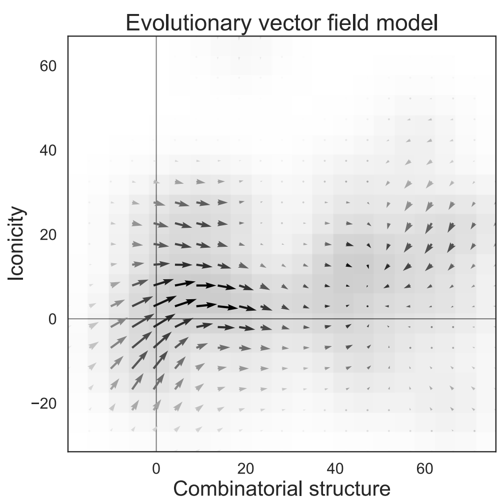


Figure 3 (Left). Vector field model describing the magnitude and direction of between-generation transmissions of languages for different combinations of iconicity and combinatorial structure. The gray shading in the background corresponds to the amount of data that is available for computing an arrow starting at that particular point. White regions represent sparse regions while darker values correspond to more data, i.e., higher confidence in the reconstructed direction and magnitude.

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