The evolution of phonological dispersion: New experimental results

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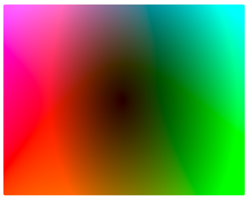
Phonological inventories seem to exhibit greater structure than expected by chance, with dispersion in vowel spaces being a well-known example (De Boer, 2000; Lindblom, 1986; Lindblom & Maddieson, 1988). How does such structure emerge and evolve? One hypothesized explanation is that dispersed systems are a response to pressures acting on perceivers—dispersal aiding distinctiveness—and on producers—with articulations at the edges of the space being easier to produce reliably (Liljencrants & Lindblom, 1972; Schwartz, Boë, Vallée, & Abry, 1997). However, the space where such dynamics play out is not uniform, and we might expect a number of factors to modulate the process, including noise, and transitions between units in production (De Boer, 2016; Carré, 2009). This account is not specific to language, suggesting that the same factors should lead to the emergence of similar structure in non-linguistic communication systems.

Roberts and Clark (2020, 2023) investigated this by having pairs of participants play a computer game in which they took turns to communicate silhouettes of animals using colors. The sender on a given turn moved a finger around on a trackpad to select series of colors from a continuous underlying colorspace. The structure of the colorspace was manipulated to vary whether the most reliably locatable areas of the trackpad for the sender lined up with the most distinct colors. They found higher dispersion than would be expected by chance, driven in large part by perceptual demands. Communicative success was lower when production and perception demands were less aligned. Roberts and Clark (2023) analyzed the process by which dispersion came about, finding it was not planned from the start but emerged as a consequence of small-scale choices and adjustments over time.

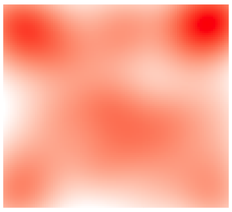
We replicated Roberts and Clark (2020, 2023) with several changes ($N = 160$). First, the colorspace was redesigned so that,in one condition, distinct colors were available throughout the space, reducing bias either for or against dispersion (Fig. 1a–1b).[1] Second, we manipulated the presence of noise, operationalized as random color deviation. Third, we manipulated the minimum number of colors (1 vs. 2) that a signal had to contain. All conditions were crossed.

[1]NB: Colors in image may seem more indistinguishably dark than reality if viewed from a distance.

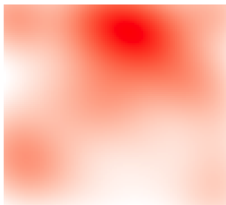
(a) Light-center colorspace



(b) Dark-center colorspace[1]



(c) Heatmap for light-center, high-noise, 2+ color condition



(d) Heatmap for dark-center, low-noise, 1+ color condition

Figure 1. Example colorspaces and heatmaps of signal-initial selections.

We measured dispersion as mean pairwise distance between signal units. This was significantly greater than chance across conditions, $\beta = 0.074, SE = 0.02, t = 4.52, p < 0.001$ It was greatest in the light-center, noise, and 2+ minimum-length conditions. Fig. 1c–1d shows heatmaps of coordinates for color selections for maximally and minimally dispersed combinations of conditions. A linear model with mean pairwise distance between signal coordinates as DV, noise and minimum signal length as predictors, along with interaction terms, did not find a significant effect ($p > 0.6$). Signal-initial colors were in fact more extreme than later colors, but this within-signal effect seems to have evened out over the inventory as a whole. The lack of an effect of noise is likely due to the communication medium already being sufficiently noisy that participants were responding to noise across all conditions.

A mixed model with mean pairwise distance as dependent variable and colorspace as predictor, with random intercepts for noise and minimum signal length, found a significant effect: $\beta(74) = 0.06, SE = 0.02, t = 2.79, p < 0.01$. These results (taken together with earlier work) suggest that phonological dispersion may be best explained as resulting from communicative pressures interacting with the topology of the signaling space (cf. Schwartz et al., 1997).

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References

Carré, R. (2009). Dynamic properties of an acoustic tube: Prediction of vowel systems. *Speech Communication*, *51*(1), 26–41.

De Boer, B. (2000). Self-organization in vowel systems. *Journal of Phonetics*, *28*(4), 441–465.

De Boer, B. (2016). Modeling co-evolution of speech and biology. *Topics in Cognitive Science*, *8*(2), 459–468.

Liljencrants, J., & Lindblom, B. (1972). Numerical simulation of vowel quality systems: The role of perceptual contrast. *Language*, *48*(4), 839–62.

Lindblom, B. (1986). Phonetic universals in vowel systems. *Experimental phonology*, 13–44.

Lindblom, B., & Maddieson, I. (1988). Phonetic universals in consonant systems. *Language, Speech, and Mind*, 62–78.

Roberts, G., & Clark, R. (2020). Dispersion, communication, and alignment: An experimental study of the emergence of structure in combinatorial phonology. *Journal of Language Evolution*, *5*(2), 121–139.

Roberts, G., & Clark, R. (2023). The emergence of phonological dispersion through interaction: An exploratory secondary analysis of a communicative game. *Frontiers in Psychology*, *14*, 1130837.

Schwartz, J.-L., Boë, L.-J., Vallée, N., & Abry, C. (1997). The dispersion-focalization theory of vowel systems. *Journal of phonetics*, *25*(3), 255–286.