THE EMERGENCE OF PHONOLOGY-LIKE ORGANIZATION IN A QUASI-PHONETIC SPACE

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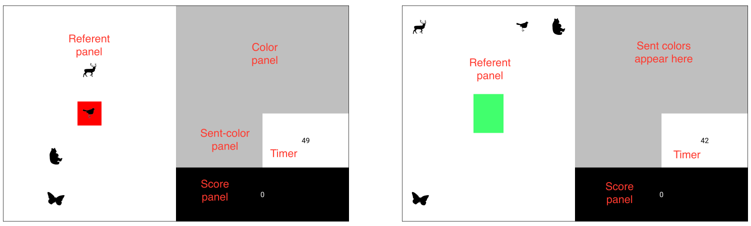
It has long been observed that phonemes are not sampled at random from available phonetic space but are rather well dispersed (Boer, 2000; Lindblom, 1986; Lindblom & Maddieson, 1988). Vowel spaces are a good example. One hypothesized explanation is that well dispersed systems allow phonemes to be distinguished more easily (Liljencrants & Lindblom, 1972; Schwartz, Boë, Vallée, & Abry, 1997). However, phonemes located closer to the edges of the space are also easier for speakers to locate reliably. We conducted an experiment to investigate the role of interactive processes in the emergence of "phonological" organization in a novel communication medium, manipulating the extent to which perceptual demands aligned with production demands.



(a) Sender's screen (b) Receiver's screen

Figure 1.: Screenshots from the game

60 undergraduates played a referential game in pairs. Players took turns to be *Sender* and *Receiver*, with the Sender communicating animal silhouettes. This involved moving a finger around on a trackpad, causing colors to appear in an onscreen *Color panel* (Fig. 1a). The Sender could select colors by holding their finger in place for 1s, causing the color to appear on the Receiver's screen (Fig. 1b) for 2s. The Sender could send as many colors as they wanted within 20s, and the Receiver had to select the right animal. Each color was composed of red, green, and blue components, the contribution of each ranging from 0 to 1. Fig. 2 shows

examples of how finger-position corresponded to colors (though neither player ever saw the whole space in this way; the relationship between specific xy dimensions and color-components was counterbalanced. Initially the pair communicated about four referents; if they successfully communicated each referent at least 75% of the time, four more were added, up to a total of 12. We manipulated how well production pressures aligned with perceptual pressures: In the *Outer-edge* condition, brighter easier-to-distinguish colors were located around the edge of the trackpad and were thus easier for the Sender to locate reliably. In the *Inner-edge*, the brightest colors were around a harder to locate "inner edge".

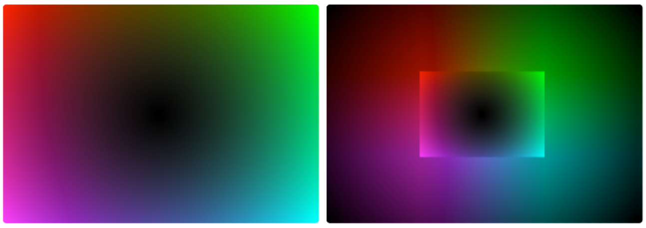


Figure 2.: Colorspaces for Outer-edge and Inner-edge conditions

We identified repeated "phonemes" across signals using Pillai scores (for a discussion of their use to identify merged and unmerged vowels in sociolinguistics, see Nycz & Hall-Lew, 2013). We then measured dispersion in terms of mean pairwise distance and distance from center, as well as mode brightness (the brightness of the brightest component in the RGB space). We calculated a success index as $(\sum_1^{n_r} s)/12n_r$, where n_r is the number of rounds and the numerator is a cumulative count of s, the number of successfully established "words" in a given round. Participants in the Inner-edge condition found the game harder and levels of dispersion in the "articulatory" space were significantly lower, suggesting that perception was guiding production; interestingly, however, mode brightness was also lower in the perceptual space, suggesting that participants were not simply maximizing perceptibility, but were having to find a compromise between perception and production demands. Dispersion in the production space was at greater than chance levels in the Outer-edge condition, but not the Inner-edge condition. Success was significantly correlated with dispersion across conditions, but not within conditions. This suggests success was driven not by dispersion per se, but by the alignment between the demands acting on the producer and the perceiver. This suggests we should expect the location of phonemes to be driven not by dispersion alone, but by the extent to which production and perception are mutually reinforcing, consistent with theoretical models in which the topology of the signaling space plays an important role (Stevens & Keyser, 2010; Carré, Divenyi, & Mrayati, 2017; Schwartz, Abry, Boë, Ménard, & Vallée, 2005)

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