Evolving a higher efficiency lexicon: High resource-cost sounds are preferentially allocated to word beginnings and stressed syllables

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Sound categories differ in the amount of effort required to produce an easily perceptible signal. For example, /k/ is a relatively low resource-cost sound, while /g/ is higher cost because it requires more physiological effort to maintain voicing at the velar position in the vocal tract. This greater cost has been linked to the observation that costly sounds like /g/ are not only more likely to be absent from a language's phoneme inventory, but also less frequently encountered within languages that have them (Everett 2018, 2020). In an information transfer system in which symbols have different costs, communication is most efficient when costly symbols are less frequent overall, while at the same time being preferentially allocated to positions in which they can convey the most information (Zipf 1949, among many others). Relative greater use of high cost sounds in potentially information rich positions results in a more balanced range of sound contrasts at these positions, creating a higher entropy (i.e., more informative) lexicon overall (Shannon 1949). Here we show that higher cost sounds are preferentially allocated to two disparate positions which are high information for entirely different reasons, creating a higher entropy system in positions where it matters most.

(i) Word position: Listeners process sounds incrementally, where each successive sound gives a listener information that helps exclude incompatible words as the speech stream progresses (van Son & Pols 2003; Magnuson et al. 2007). As a consequence of this progressive exclusion, sounds early in a word convey on average more information than those later in the word (King & Wedel 2020).

(ii) Syllable stress: Stressed syllables tend to be more perceptually salient than unstressed syllables, for example by being longer, louder, and/or higher pitched

(Gordon & Roettger 2017). Through these combinations of attributes, stressed syllables provide a superior platform for the perception of phonetic cues, independently of their position in the word.

We assembled a data set of nine genetically diverse phonemically coded languages as a basis for testing the hypotheses that higher-cost sounds are preferentially allocated (i) to word beginnings, and (ii) to stressed syllables. As a proxy for resource-cost, we employed the usage rate of a phoneme within languages, that is, the lexical type frequency of a phoneme (Everett 2018). As predicted, we find a highly significant relationship between usage rate of sounds (on the y-axis) and syllable number (on the x-axis) in this data set, that is, higher cost sounds occur most often in early syllables, all else being equal (Figure 1).

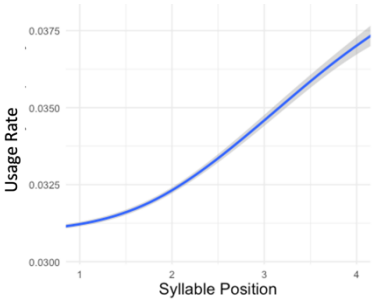

Figure 1. Usage rate by syllable position in the word. Usage rate is lower early in the word indicating greater average cost.

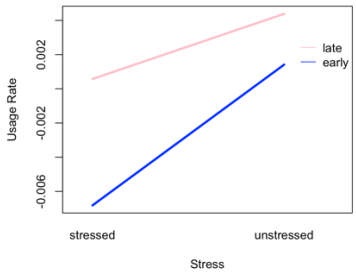

Figure 2. Usage rate by syllable stress level. Stress is associated with lower usage rate, especially at word beginnings.

In addition, we find that stressed syllables are significantly associated with a greater proportion of low usage rate sounds, corresponding to a greater entropy system in stressed positions (Piantadosi et al. 2009). This effect significantly interacts with word position in this dataset: it is strongly negative at the beginnings of words but less so at ends, where the potential to convey information is necessarily lower due to incremental processing (Figure 2; note that usage rate is higher overall late in the word). At the beginnings of words, at which the potential to convey information is high, there are significantly more low usage rate sounds in stressed relative to unstressed syllables. How does this arise? High-information sounds tend to be hyperarticulated, while lower-information sounds tend to be reduced or deleted (e.g., Kanwal et al. 2017, Wedel et al. 2019). Through this process, we expect information-rich positions to more often retain high cost sounds over time, leading over time to a lexicon which is more efficient in its distribution of sounds over words (Dautriche et al. 2017; Gibson et al. 2019).

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