Modeling new conceptions of functional load with perceptual confusability
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In linguistics, functional load was first proposed as a way of predicting historical phoneme loss. Traditionally, accounts of functional load have eschewed behavioral and perceptual data, focusing on written or transcribed corpora to estimate it. More recently, theories have embraced the gradient nature of phone recognition, and have investigated the interactions between the lexicon, perceptual information, and language change (e.g. Hall, 2009). As new studies demonstrate the importance of incorporating perceptual information into accounts of functional load (e.g. Tsui, 2012), the question arises as to how one can simulate these interactions. In this paper, I outline a simple exploratory model capable of simulating the complex interactions of perceptual confusability, the lexicon, and language change, ultimately using the model to produce a measure similar to traditional conceptions of functional load, but with three key differences.

Some studies have used forms of entropy to measure how a phonemic contrast loss affects the system, but in this paper I choose to use word recognition, a different—albeit related—measure, under the theoretical assumption that overall communicative effectiveness presents a stronger pressure on language change. In order to simulate how word recognition is affected by contrast loss, I estimate the probability of correct word recognition with a form of the Frequency-Weighted Neighborhood Probability Rule (Luce & Pisoni, 1998). Here, the perceptual confusability of a word is weighted by its log frequency, and divided by the sum of its phonetic confusability with its neighbors weighted by their log frequencies. To calculate the phonetic confusability of two strings of phones, the model multiplies the confusabilities between phones in the first string with phones at the same locations in the second string, using probabilities from a phonetic confusion matrix.

I established this confusion matrix using phonetic confusion data from Cutler et al. (2004) and Woods et al. (2010). Combining the perceptual confusion data with a lexicon from the SUBTLEX-US database (Brysbaert & New, 2009), I estimated the probability of correctly recognizing ~42,000 word forms of English. To simulate contrast loss in the model, one merely needs to manipulate the phonetic confusion matrix. To completely remove the contrast between /ɑ/ and /ɔ/ for example, one distributes the probability mass of the /ɑ/ and /ɔ/ cells so that P(/ɑ/|resp)P/ɔ/|stim)=P(/ɔ/|resp)P/ɑ|stim) and vice versa. This simple model can generate measures similar to functional load, but with three key differences.

To begin with, phones differ in their ease of recognition and differentiation acoustically and perceptually (Miller & Nicely, 1955). Some phones are harder to correctly recognize than others, and some contrasts are more readily confused. If one looks at functional load on the word-level of spoken language (that is, if one cares about distinguishing between spoken words), then the amount of confusion in the communication system that is generated by losing different contrasts depends on the a priori perceptual confusability of the phones of the contrast, a fact generally avoided in discussions of functional load.

A contrast loss between two phones with high perceptual confusability will affect word recognition less than a contrast loss between two very perceptually distinct phonemes, all things being equal: highly confusible phonemes provide less informative cues for word recognition and their removal will therefore impact the system less. The importance of incorporating a priori perceptual confusability into functional load is illustrated by Tsui (2012), which demonstrated that combining acoustic similarity with functional load correctly identified mergers that functional load alone could not.

To test if the model captures the effects of a contrast’s a priori confusability, I compared the overall decrease in word recognition from removing the /ɑ/-/ɔ/ contrast in American English (where it has highly confusable naturally) to an artificial version of English wherein
/ɑ/-/ɔ/ were much more perceptually distinct (created by reducing their a priori confusability by 80% in the matrix). As predicted, the model captures the difference between the two systems: removing the contrast when the phones are perceptually dissimilar increases the mean chance of word misrecognition by 10.1%, whereas removing the contrast in the natural version increases the mean by 6.6%.

In the same vein, previous studies of functional load have focused on situations in which contrasts are completely removed. That is, they compare the language with or completely without the contrast (for an exception, see Hall, 2009). Note that this model lets the researcher easily examine how partial contrast loss affects the language system. To simulate how word misrecognition increases as a contrast is lost over time, Fig. 1 plots the increase in overall misrecognition as the /t/-/d/ contrast is lost in intervals of 10% of the full loss. We see that the increase in overall misrecognition is fairly constant for each step, although the small differences in the derivative of the increase at each step suggest that the increase in misrecognition increases as the contrast comes closer to disappearing, up to a point (Fig. 2).

Finally, even more recent measures of functional load fail to capture the fact that real-world word recognition is strongly influenced by non-minimal pair phonological neighbors, which can also be affected by contrast loss. For a simple illustration, consider the words "got" and "caught". In American English dialects without the "cot-caught" merger, /ɑ/ and /ɔ/ are still highly confusable. In such a dialect, imagine removing the contrast between /k/ and /g/. Although "got" and "caught" are not minimal pairs, removing the voicing distinction would make them highly confusable and would severely impair correct word recognition. Comparing how the /g/-/k/ contrast loss affected word recognition in the current model versus a model in which only minimal pairs could be considered as possible alternatives, I found that the mean probability of misrecognizing words containing /ɡ/ or /k/ was 0.023 when only minimal pairs were considered, but approximately three times as much when phonological neighbors were factored into the model.

In Hong Kong Cantonese, several tones appear to be undergoing mergers (Mok et al., 2013). Nonetheless, speakers still differentiate these tones in their production and comprehension (albeit significantly less than their non-merging counterparts). Traditional conceptions of functional load prevent investigation of a variety of aspects of these mergers. For example, traditional measures would predict that both Hong Kong Cantonese and non-merging dialects would have the same chance of completely losing these tonal contrasts, even though Hong Kong Cantonese has already partially lost them. Such measures would fail to take into account the a priori greater tonal confusability currently present in the Hong Kong dialect. Or, for example, if one would want to estimate the amount of overall communicative confusion already generated by these partial mergers, one would be unable to do so. The current model lets researchers address all of these questions and more.