Is the phonetic signal mapped directly to phonological feature categories? Investigating the perceptual basis of vowel height

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Phonological features are abstract linguistic representations named after physical properties of speech sounds. In phonological descriptions of vowel systems, a direct relation is assumed between a phonological feature and its phonetic correlate. The question remains whether such direct relation between features and phonetics exists also in the grammars of language users (Ladefoged, 1980, *Language*). Recent experiments with humans, as well as computer simulations, indicate that listeners map phonetic signal onto phonological feature categories (e.g. Scharinger et al., 2011, *J Cogn Neurosci*; Lin & Mielke, 2008, *UPenn Work Papers Ling*). However, these previous studies did not explicitly compare a feature- and a phoneme-based model of perception.

The present study addresses the feature vs. phoneme issue directly: we test whether listeners map phonetic information onto features or onto phonemes. We computationally implemented a feature and a phoneme model of perception. The implementations modeled the possible grammars of listeners with a typical 5-vowel system (i, e, a, o, u), in which vowels are contrasted by 3 height and 3 backness feature values (high, mid, low; front, mid, back). We simulated how the models discriminate stimuli in the F1-F2 vowel space: for every F1-F2 sample, we computed the probability of scoring “different” for two identical stimuli. Fig. 1 shows that the models yield different discrimination patterns: the phoneme model divides the vowel space into 5 categories, while the features model divides it into 9 categories (i.e. the 9 possible combinations of the height and backness feature values).

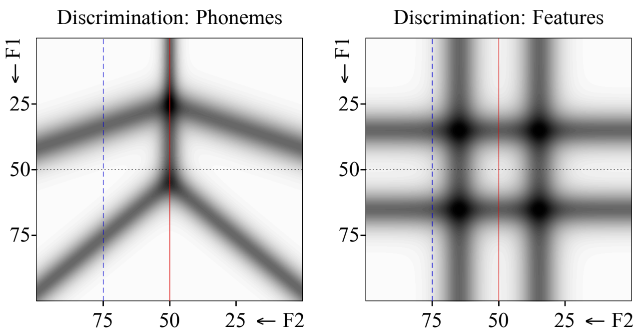

Fig. 1: Modeled discrimination of the vowel space. White = low discrimination score, black = high discrimination score. The red solid and the blue dashed line show the central and front continuum, respectively, which are displayed in Fig. 2. Note that F1 and F2 have arbitrary scales from 0 to 100.

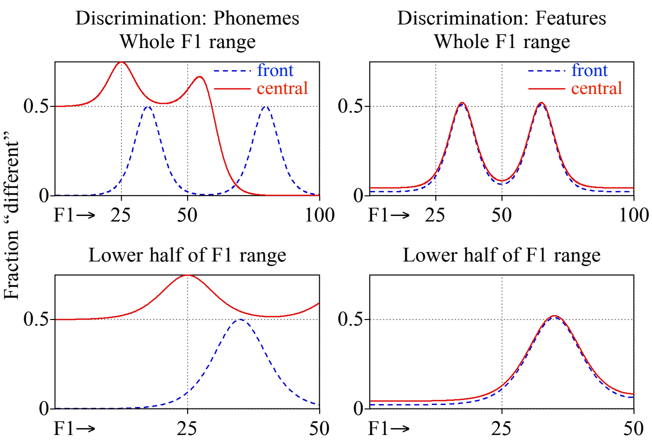

Fig. 2: Modeled discrimination of the front and the central continuum. Top = discrimination of the whole F1 range (i.e. including the low feature or the phoneme /a/, cf. 2-peak listeners in Fig. 3). Bottom = discrimination of the lower half of the F1 range (i.e. involving only the high and the mid feature, or the phonemes /i, e, u, o/, cf. 1-peak listeners in Fig. 3).

Fig. 2 shows that the feature model yields similar discrimination on both a front a central continuum: there are peaks of high discrimination between adjacent sounds as well as troughs within which discrimination is near 0. This discrimination result reflects that the model perceives the same height contrast on the front and on the central continuum: namely, highfront–midfront(–lowfront) and highcentral–midcentral(–lowcentral, respectively). A similar discrimination pattern is seen in the phoneme-model for the front, but not for the central continuum. On the central continuum, the phoneme model has peaks at lower F1 values, because the phoneme /a/ occupies a large part of the central continuum. In addition, the phoneme-model considers two acoustically identical stimuli (at the lower half of the F1 range) to be different in 50% of the time. This pattern arises because the central continuum is exactly at the /i/-/u/ boundary, and the phoneme model has a 50/50 chance of perceiving the same stimulus as either /i/ or /u/. Note that if the central continuum is slightly away from a listener's individual /i/-/u/ boundary, the 50% discrimination is not expected anymore, but the predicted difference in the peak locations persists. Taking into account these different predictions of the two models for the front and the central F1 continuum, we assessed vowel discrimination in human listeners.

In listeners with a 5-vowel system (Czech), we first determined the average F2 of the boundary between front and back vowels (i.e. the F2 value of central continuum), and created three F1 continua: front, back, and central. Stimuli in each of these continua differed along the F1 dimension ranging from 280 to 725 Hz in 130 steps. If humans are feature-listeners, they should have similar discrimination peaks and troughs on the front, back, and central continuum. If they are phoneme-listeners, their discrimination of the central continuum should differ from that of the front and back continua: namely, they should have peaks at higher F1 values.

Participants (*n*=81) were tested in a same-different task with stimuli from one of the three continua, and we subsequently assessed the number of obtained discrimination peaks (i.e. the number of perceived category boundaries), as well as their height, width, and location (i.e. the crispness and location of the category boundaries). Perception on each continuum yielded significant discrimination peaks and the number of peaks was comparable across the three continua: half of the listeners had 1 peak, and about a third of the listeners had 2 peaks (see Fig. 3). In 1-peak listeners, we did not find any significant differences in peak parameters between the central and other continua. In 2-peak listeners, we found that the second but not the first peak was at a lower F1 in the central continuum than in the other continua. The results of 1-peak listeners thus resemble the modeled feature listeners, while the 2-peak listeners resemble partly the modeled feature- and partly the modeled phoneme listeners. Taken together, our findings indicate that listeners may map the incoming phonetic information onto feature categories, but at the same time, this perceptual mapping seems to involve phoneme categories as well.

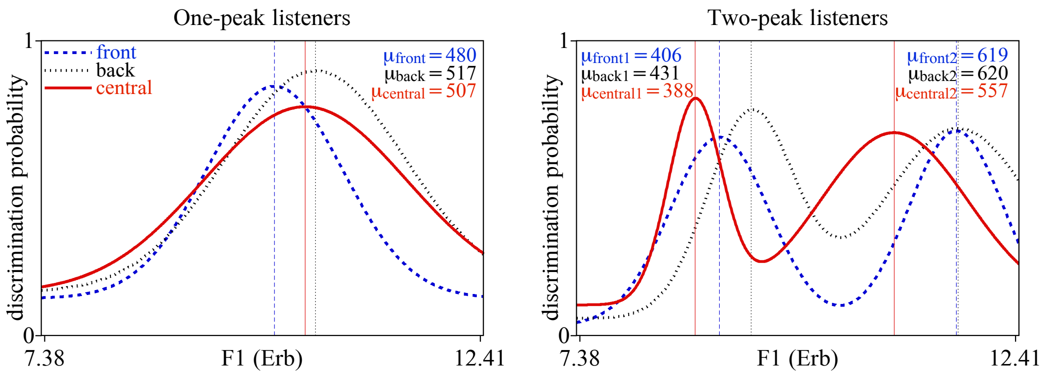

Fig. 3: Discrimination of the 3 continua by humans. In the F1 stimulus range, some listeners perceived 2 height categories (high/mid; 1-peak listeners), while others perceived all their 3 native height categories (high/mid/low; 2-peak listeners).