Many of the acoustic attributes which act as indicators of phonological contrasts involve dynamic properties operating at roughly the time-scale of an individual segment. Because of this similarity in time scale, these dynamic properties are pervasively subject to the articulatory effects of tempo modulation. However, various research threads over the past 30 years have also shown pervasively that listeners are very proficient at accounting for the effects of tempo modulation in retrieving phonological information (for example, Volaitis & Miller, 1992, for Voice Onset Time (VOT), and Pind, 1995, for vowel duration and quantity). This, then, raises the question of whether tempo modulation effects, though pervasive, are relevant for phonological systems.

The current paper presents the results of two experiments designed to interlock production and perception, 1) a production study of how tempo modulation affects the articulation of the plosive laryngeal contrasts in prevocalic and postvocalic positions in American English, and 2) a perceptual study of how such productions are identified.

**1) Production:** Productions of syllables were elicited through a motor control task entraining speakers to metronomic pacers at various stable and moving rates. Since this is conceived of as a motor task, the range of rates examined is quite extreme, ranging from 450ms/syllable to 150ms/syllable. Acoustic analyses find pervasive, complex, and non-linear effects of tempo modulation on the aspects of the signal associated in perceptual studies with the laryngeal contrast.

A detailed analysis of VOT for prevocalic stops (Figure 1) reveals extreme variation in VOT productions (y-axis) of /p/ (solid markers), and a positive scaling of the VOT values relative to overall tempo (indexed by syllable duration on the x-axis). This scaling function, however, is not proportional to the tempo variation, so that expressing VOT as a ratio of syllable duration overestimates the tempo effect. Productions of /b/, which in this corpus are produced without prevoicing (hollow markers), reveal mildly negative scaling of VOT values, so that fast productions actually have slightly longer VOT values than slow productions.

Analyses of productions of post-vocalic consonants reveal still different patterns. Closure duration of the plosives and preceding vowel duration also vary extensively by tempo. Here the variation is more linear, but still is not proportional, which suggests that a fixed ratio cannot be used for rate normalization.

**Figure 1.** VOT as a function of syllable rate for /p/ (filled), and /b/ (hollow).
2) **Perception.** In order to determine the effect of these tempo modulations, 336 excised three-syllable productions were presented to 48 listeners in related speech identification experiments. Perceptual responses to prevocalic stimuli show that listeners are keenly attuned to tempo modulations, yielding an overall accuracy rate of 84%. Most of the errors involve misperceptions of /b/ stimuli as /p/ in fast rate productions. These errors are clearly not accounted for by raw VOT values, as is indicated in Figure 2, which plots VOT as a function of the proportions of /p/ percept. VOT values for misperceived /b/s (hollow symbols to the right) have similar values to those unambiguously perceived as /b/ (hollow symbols to the left).

These misperceptions can be accounted for by incorporating overall tempo in the analysis, showing that fast-rate productions involve an extension of the perceptual function from the slower-rate /p/ productions. This function is too aggressive, underestimating the VOT boundary dividing /p/ and /b/ in the extremely fast end of the distributions, thus creating a mismatch between the produced and perceived categories.

This mismatch between production and perception appears to have roots in production, such that the production of /b/ at fast rates exhibits unusual increases in VOT due to aerodynamic effects of the closing vocal tract. In addition, it also has roots in the perceptual normalization of the widely varying /p/ being overgeneralized in the fastest rates. The pairing of the production and perception experiments shows, then, a systematic /b/ to /p/ bias for prevocalic plosives, which only comes out with matching production and perception experiments.

Similar effects occur with post-vocalic plosives, except in the opposite direction. Here, most of the fast-rate productions exhibit the reverse categorization mismatch, such that produced /p/ is perceived as /b/. The paper concludes by pointing out that such opposite directional biases in perception, /b/ to /p/ in prevocalic position, but /p/ to /b/ in post-vocalic position, mirror the typical effects of syllabic position in phonological systems; onset segments tending to be shifted toward the voiceless and aspirated direction, and coda segments tending to be shifted toward the voiced and unaspirated direction. Thus, production and perception experiments in an interlocking design seems a useful approach for uncovering what production effects might contribute to phonological systems.