Vowel movement as a function of voicing in simple CV sequences

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The articulatory and acoustic correlates of stop voicing contrasts have been shown to be many and varied (e.g., Brunner, Fuchs, Perrier & Kim, 2003; Lisker, 1986). One of these is to be found in the velocity of the vocalic gestures of the tongue. Earlier ultrasound studies based on limited stimuli and subjects suggest that these gestures are faster and achieve their targets earlier after voiced than after voiceless stops (Ostry, Keller & Parush, 1983). It is not yet known whether this binary distinction between voiced and voiceless stops extends to aspirated stops and in particular whether the gradient differences in voice-onset-time (VOT; the relative timing of the release of an oral stop and the onset of periodic vibration of the vocal folds) also determine aspects of the vocalic gesture. It also remains to be seen whether the articulatory initiation of the vowel (i.e. the start of the movement of the major articulator for the vowel) is sensitive to different voicing conditions and especially to different degrees of VOT.

In our investigation, we present the first examination of vowel initiation in CV sequences as a function of C voicing (voiced vs. voiceless) across different places of articulation. In past work, it has been shown that vowels start later when preceded by voiceless aspirated stops than when preceded by voiceless unaspirated stops (Sotiropoulou, 2014 on /pV/~spV/). This raised the question of whether the vowel movements of the tongue occur later relative to consonant closure release after voiceless than after voiced consonants (i.e. /pV/ vs. /bV/). We furthermore hypothesize that among aspirated stops, a later achievement of the laryngeal abduction gesture target, with its resulting longer VOT (see Löfqvist & Yoshioka, 1984; Sawashima & Hirose; Tobin, 2015), will yield slower achievement in the vocalic gesture target.

Acoustic and articulatory data were registered from four native speakers of American English using a NDI Wave yielding a total of 522 tokens. Stimuli consisted of word-initial voiced and voiceless singleton onsets (e.g., beach-peach) at the labial, alveolar, and velar place of articulation (e.g., bought, dock, caught) in high and low vowel contexts (e.g., beach, bought). Gestural landmarks were identified using the algorithm developed by Mark Tiede at Haskins Laboratories (using velocity thresholds). We measured vowel initiation relative to the release of the preceding consonant. Subsequently, we ran a Principle Component Analysis to reduce the dimensionality of the tongue dorsum sensor from three to one, and velocity profiles were computed from the resulting movement trace for each trial.

Functional mixed effects models (Morris & Carrol, 2006) of the velocity profiles and a univariate linear mixed effects model for the duration confirm that the vocalic gesture is faster and of shorter duration for voiced than for voiceless stops in both high and low vowel contexts. Additionally, as shown in Figure 1, we found a negative correlation (r (203) = -0.52) between vocalic gesture velocity and VOT in voiceless aspirated stops: longer voiceless stop VOTs (i.e., later laryngeal target achievement) were followed by slower vocalic gestures.

Figure 1: Relative VOT (y axis) by velocity V (x axis) among aspirated stops, showing a negative correlation: the longer the VOT, the slower the velocity of vocalic gesture.
Figure 2 below shows lag durations (in ms) of vowel initiation with respect to the release of the preceding consonant. Larger negative values mean that the vowel starts earlier while positive values indicate later vowel initiation. The vocalic gesture started earlier following voiced (left) vs. voiceless stops (right). Additionally, vowel initiation seems to be sensitive to gradual VOT differences. For voiceless labials (right) with short VOT vowel initiation occurs earlier relative to the consonantal release, while for voiceless velars with long VOT the vowel starts later relative to the consonantal release.

![Figure 2: Lag duration (in ms) expressing vowel initiation relative to the release of the onset consonant (labial, alveolar, velar) in voiced (left) and voiceless (right) CV sequences of high (white bars) and low vowel (grey bars) context.](image)

Oral-laryngeal coupling in onsets has been observed to maintain tight temporal coordination even under the effect of oral perturbation (Munhall, Löfqvist & Kelso, 1994). More specifically, achievement of the tongue’s vocalic target is critically timed with the laryngeal adduction gesture, which is achieved later following voiceless stops than voiced. In our findings, the critical timing of oral and laryngeal gestures with the vocalic gesture shows up in vowel initiation and vowel velocity. In particular, we found that later achievement of the adduction gesture (long VOT) yields later vowel initiation and slower achievement of vocalic target. Finally, our findings inform the design and evaluation of stimuli sets for future phonological studies using kinematic data. In particular, they make clear that controlling for place of articulation of the preceding consonant, especially in studies where C-V timing is crucial, is insufficient in also controlling for C-V combination specific effects on the kinematic records. The voicing of the consonant has an effect on when the vowel starts and on how that vowel unfolds in time.

References