Effects of Vocal Effort on Respiratory and Articulatory Kinematics

Defne Abur[1], Joseph S. Perkell[1,2], and Cara E. Stepp[1,3,4]

[1]Department of Speech, Language, and Hearing Sciences, Boston University, Boston, MA
[2]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA
[3]Department of Biomedical Engineering, Boston University, Boston, MA
[4]Department of Otolaryngology – Head and Neck Surgery, Boston University School of Medicine, Boston, MA

Rationale and Purpose: Vocal effort is the "perceived exertion" that is "experienced by the speaker" [1] and it is one of the most prevalent symptoms reported by speakers with voice disorders and speakers who are high voice users [2]. Yet the mechanisms underlying vocal effort are not fully understood. Physiological changes at the laryngeal level due to vocal effort have been studied extensively in both speakers with typical voices and speakers with voice disorders [e.g., 3]; however, approaches to understanding the roles of the respiratory and articulatory subsystems have been more limited and varied. Prior work suggests a relationship between increased vocal effort and respiratory kinematics [4] and articulatory-acoustic measures of speech [5], but articulatory kinematics have not been examined with respect to vocal effort. Further, speakers with typical voices exhibit concurrent changes in speech intensity when increasing vocal effort [6] and speech intensity has shown articulatory-kinematic manifestations during speech [7, 8]. The purpose of the current study was to investigate how increases in vocal effort, while maintaining steady speech intensity, impact 1) respiratory kinematics during speech initiation and termination, as well as 2) articulatory kinematics of tongue and lip displacements during speech.

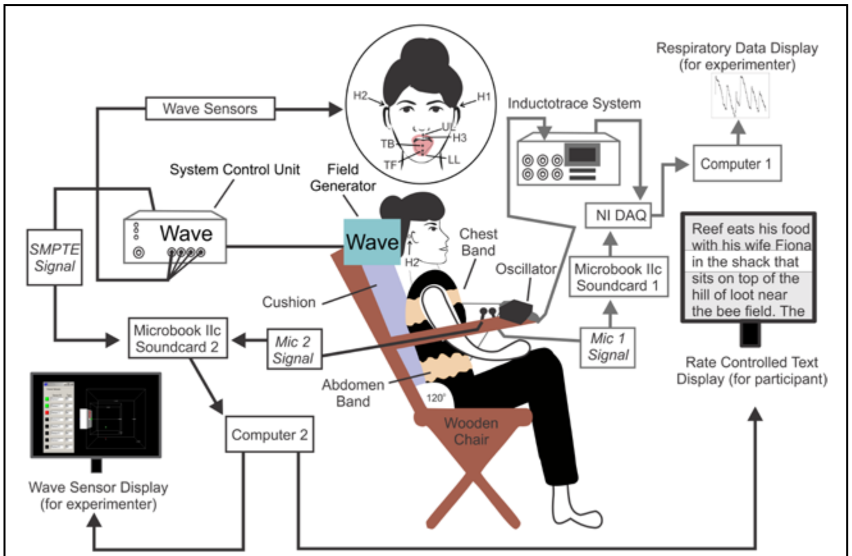

Figure 1: Experimental setup.

Methods: A total of 10 young adults (5 female, 5 male) completed a rate-controlled reading passage under three speaking conditions (baseline, mild vocal effort, maximum vocal effort) while wearing movement sensors on the face, as well as respi-bands around the chest and abdomen (see Figure 1). Electromagnetic articulography and inductance plethysmography were used to examine: lung volumes at speech initiation (LVSI) and at speech termination (LVST), articulatory-kinematic vowel space (AKVS) of the tongue back (TB) and tongue front (TF) sensors, and lip aperture for each reading of an experimental text. Lung volumes were expressed as a percent of each speaker's maximum excursion relative to their tidal resting expiratory level. A non-parametric Friedman test was conducted to assess differences among repeated measures for each of the respiratory- and articulatory-kinematic outcome variables. Wilcoxon signed-rank tests were used to determine statistically significant differences between each speaking condition.

Results: There was a statistically significant effect of effort condition on LVSI (*df* = 2, Chi-Square = 16.20, $p < 0.001$) with a large effect size (Kendall's w = 0.81). *Post hoc* analyses revealed statistically significant differences in LVSI between all the speaking conditions. No statistically significant effects of condition were found for LVST or the AKVS measures. For lip aperture, there was a statistically significant effect of condition (*df* = 2, Chi-Square = 12.20, $p = 0.002$), with a large effect size (Kendall's w = 0.61). *Post hoc* analyses showed a statistically significant difference between the baseline and maximum vocal effort condition (W(10) = 0, $p = 0.006$), but no statistically significant differences between the other conditions.

Conclusion: Respiratory and articulatory kinematics were examined during increases in vocal effort, without changes in speech intensity, in speakers with typical voices. The current findings suggest that most speakers exhibit larger lung volumes at speech initiation during increases in vocal effort paired with reduced lip displacements, but no changes in lingual movements. To our knowledge, this is the first study to provide evidence of coordination of the laryngeal and articulatory systems in speakers with typical voices who are modulating vocal effort; this observation should be examined in future work.

References

1. Hunter, E.J., et al., *Toward a Consensus Description of Vocal Effort, Vocal Load, Vocal Loading, and Vocal Fatigue.* Journal of Speech, Language, and Hearing Research, 2020. **63**(2): p. 509-532.
2. Roy, N., et al., *Voice disorders in the general population: Prevalence, risk factors, and occupational impact.* Laryngoscope, 2005. **115**(11): p. 1988-1995.
3. McKenna, V.S., et al., *The relationship between relative fundamental frequency and a kinematic estimate of laryngeal stiffness in healthy adults.* Journal of Speech, Language, and Hearing Research, 2016. **59**(6): p. 1283-1294.
4. McKenna, V.S., et al., *Magnitude of neck-surface vibrations as an estimate of subglottal pressure during modulations of effort and intensity in healthy speakers.* Journal of Speech, Language, and Hearing Research, 2017. **60**: p. 3404-3416.
5. Roy, N. and N.A. Ferguson, *Formant frequency changes following manual circumlaryngeal therapy for functional dysphonia: Evidence of laryngeal lowering?* Journal of Medical Speech-Language Pathology, 2001. **9**(3): p. 169-175.
6. Rosenthal, A.L., S.Y. Lowell, and R.H. Colton, *Aerodynamic and acoustic features of vocal effort.* Journal of Voice, 2014. **28**(2): p. 144-53.
7. Whitfield, J.A., C. Dromey, and P. Palmer, *Examining acoustic and kinematic measures of articulatory working space: Effects of speech intensity.* Journal of Speech, Language, and Hearing Research, 2018. **61**(5): p. 1104-1117.
8. Mefferd, A. and J.R. Green, *Articulatory-to-acoustic relations in response to speaking rate and loudness manipulations.* Journal of Speech, Language, and Hearing Research, 2010.