Characterizing sensorimotor profiles in children with residual speech errors

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Rationale. Most children with speech sound disorder recover spontaneously or through therapy, but approximately 25% persist with errors past age six [1]. This amounts to approximately 1-2% of individuals continuing with residual speech errors (RSE) into adolescence/adulthood [2], which can result in lifelong obstacles. Knowing which factors predict who will persist with errors beyond childhood is a crucial step toward making evidence-based clinical decisions for this population. Those children with reduced motor skill are considered most likely to develop persistent errors [3], but the means available for measuring motor involvement are limited. The overall objective of this study is to evaluate a potential measure of motor skill while examining the relationship between motor and sensory factors in children with RSE affecting rhotic targets.

Background. Somatosensation has been shown to be essential for speech motor control [4]. In a model of this dependence (DIVA), speech is produced by executing a stored motor plan modulated by somatosensory and auditory feedback [5]. "Motor skill" can refer to the robustness of the feedforward plan, while somatosensory and auditory acuity are sensory factors that influence the speaker's ability to access and respond to feedback in that domain. To characterize individual skill, we measured motor, somatosensory, and auditory skill in connection with production accuracy. Motor skill was measured as an individual's degree of differentiated control of anterior versus posterior lingual regions, which has been connected with achievement of adult-like speech [6]. Somatosensory acuity can be evaluated in tasks where an individual uses their tongue to identify details about an object; this skill was found to be lower in adolescents with RSE than typically developing peers [7, 8]. Auditory acuity is known to be correlated with production precision [9, 10], so the present study controls for auditory acuity while focusing on the less-studied somatosensory domain. The first goal of this study is to understand the relationship between motor skill and perceived accuracy of speech. We then ask whether somatosensory acuity and motor skill (controlling for auditory acuity) are related.

Methods. Participants were 34 children (ages 9-14) with RSE affecting rhotic sounds who completed ten weeks of ultrasound biofeedback treatment. All were native speakers of American English with average language skills and no comorbidity. Binary ratings of perceptual accuracy for each /r/ from a standard word probe administered before and after all treatment were obtained from at least nine native English-speakers in an online forum [11]. Degree of lingual differentiation was quantified using ultrasound-based indices of "tongue complexity," measured using a modified curvature index (MCI) [12] and number of inflection points (NINFL) [13]. We recorded ultrasound video (Siemens C8-5 transducer) through a computer's video capture card, traced the tongue contour of the ultrasound frame nearest the midpoint of each acoustically-defined target interval using GetContours [14] in MATLAB [15], and calculated MCI and NINFL from the raw coordinates *(see Figure 1)*. To measure somatosensory acuity, we used an oral stereognosis task in which children used their tongue tip to identify a letter embossed on a plastic strip [16]. Letters ranging in size were presented following an adaptive staircase where size decreased after correct and increased after incorrect

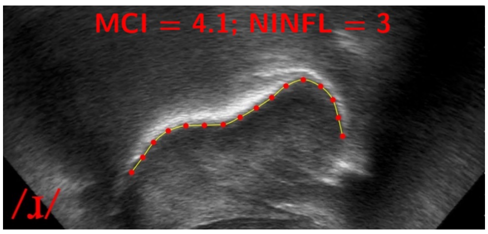

Figure 1: *Sixteen anchor points can be visualized for an /r/ target in GetContours [14].*

responses. After 8 reversals in direction, the score is the average letter size of correct trials *(see Figure 2)*. To measure auditory acuity, we administered an established /r/ versus /w/ identification task [9] to calculate an individual child's distinctness of categorization of these phonemes.

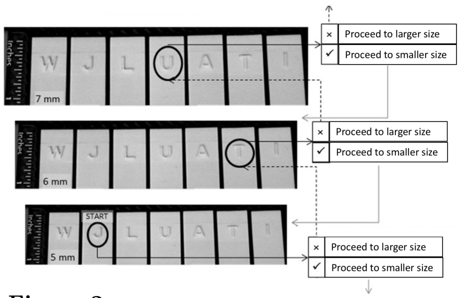

Figure 2: *Plastic letter strips in oral stereognosis task, adapted from Steele et al. [16] with permission.*

Analysis. To explore the relationship between tongue complexity and perceived production accuracy, we will fit mixed-effects logistic regression models predicting binary production accuracy from tongue complexity (MCI/NINFL) while controlling for treatment (pre/post), and including random intercepts for child and word. As accurate production of later developing targets such as /r/ is known to require differentiated tongue shapes, we hypothesize that tongue complexity will be directly associated with perceived accuracy. To explore the association between somatosensory acuity and tongue complexity, we will fit linear mixed-effects regression models predicting tongue complexity (MCI/NINFL) from somatosensory acuity, while controlling for auditory acuity, treatment (pre/post), and including random intercepts for child. We predict that children with higher somatosensory acuity will have more complex tongue shapes for /r/, consistent with the hypothesis that higher somatosensory acuity should lead to better use of somatosensory feedback in order to achieve complex articulatory targets.

Results. All sensory tasks have been scored and perceptual accuracy ratings are currently being collected. For ultrasound measurements, 33/34 pre-treatment and 24/34 post-treatment files have been processed. If tongue complexity is significantly associated with accuracy, this would suggest that tongue complexity could be a useful index of motor involvement for children with RSE. However, ultrasound-based tongue complexity is not readily obtainable in all settings. Therefore, if the hypothesized correlation between somatosensory acuity and tongue complexity is sufficiently strong, it may be preferable for clinical focus to be on the easier-to-obtain somatosensory measure. This research will ultimately contribute to understanding how sensorimotor profiles correspond with rhotic production skill in children with RSE, which could serve to help match children to the treatment approach best suited to their specific area of deficit.

References

[1] Lawrence D. Shriberg, J. Bruce Tomblin, and Jane L. McSweeny. Prevalence of speech delay in 6-year-old children and comorbidity with language impairment. *Journal of Speech, Language, and Hearing Research*, 42(6):1461–1481, 1999.

[2] Peter Flipsen. Emergence and prevalence of persistent and residual speech errors. *Seminars in Speech and Language*, 36(4): 217–223, 2015.

[3] Jennell C Vick, Thomas F Campbell, Lawrence D Shriberg, Jordan R Green, Klaus Truemper, Heather Leavy Rusiewicz, and Christopher A Moore. Data-driven subclassification of speech sound disorders in preschool children. *Journal of Speech, Language, and Hearing Research*, 57(6):2033–2050.

[4] Stéphanie Tremblay, Douglas M Shiller, and David J Ostry. Somatosensory basis of speech production. *Nature*, 423(6942): 866–869, 2003. ISSN 1476-4687.

[5] Frank H. Guenther. *Neural Control of Speech.* Massachusetts Institute of Technology, Cambridge, MA, 2016.

[6] F. E. Gibbon. Undifferentiated lingual gestures in children with articulation/phonological disorders. *Journal of Speech, Language, and Hearing Research*, 42(2):382–397, 1999.

[7] James C McNutt. Oral sensory and motor behaviors of children with /s/ or /r/ misarticulations. *Journal of Speech, Language, and Hearing Research*, 20(4):694–703.

[8] Donald J Fucci and John H Robertson. "functional" defective articulation: An oral sensory disturbance. *Perceptual and Motor Skills*, 33(3):711–714.

[9] Tara McAllister Byun and Mark Tiede. Perception-production relations in later development of american english rhotics. *PLOS ONE*, 12(2):e0172022.

[10] Joseph S. Perkell, Frank H. Guenther, Harlan Lane, Melanie L. Matthies, Ellen Stockmann, Mark Tiede, and Majid Zandipour. The distinctness of speakers' productions of vowel contrasts is related to their discrimination of the contrasts. *The Journal of the Acoustical Society of America*, 116(4):2338–2344, 2004.

[11] Tara McAllister Byun, Daphna Harel, Peter F. Halpin, and Daniel Szeredi. Deriving gradient measures of child speech from crowdsourced ratings. *Journal of Communication Disorders.*, 64:91–102, 2016.

[12] Katherine M. Dawson, Mark K. Tiede, and D. H. Whalen. Methods for quantifying tongue shape and complexity using ultrasound imaging. *Clinical Linguistics & Phonetics*, 30(3-5):328–344, 2016.

[13] Jonathan L Preston, Patricia McCabe, Mark Tiede, and Douglas H Whalen. Tongue shapes for rhotics in school-age children with and without residual speech errors. *Clinical Linguistics & Phonetics*, pages 1–15.

[14] Mark Tiede. Getcontours, 2016. `https://github.com/mktiede/GetContours`.

[15] The MathWorks, Inc. MATLAB, 2000. `https://www.mathworks.com/products/matlab/`.

[16] Catriona M Steele, Lisa Hill, Shauna Stokely, and Melanie Peladeau-Pigeon. Age and strength influences on lingual tactile acuity. *Journal of Texture Studies*, 45(4):317–323.