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Minimally detectable change of speech intelligibility in speakers with multiple sclerosis and Parkinson's disease

Stipancic, K. L. & Tjaden, K.

The minimally detectable change (MDC) is a standard method for estimating the magnitude of change on a particular rehabilitation outcome measure that is necessary to be outside of measurement error. The MDCs of outcome measures are known to differ widely across patient populations. MDCs have only recently begun to be estimated for speech outcomes and only one study has estimated the MDC of speech intelligibility in patients with amyotrophic lateral sclerosis (ALS). In this project, we calculated the MDC of speech intelligibility, as derived by orthographic transcription of the Sentence Intelligibility Test (SIT), for 78 speakers – 32 neurologically healthy control speakers, 30 speakers with multiple sclerosis (MS), and 16 speakers with Parkinson's disease (PD). To calculate the MDC at the 95% confidence level, we used standard estimating procedures with the following calculation: MDC95 = 1.96 x ?2 x standard error of measurement (SEM). We found an MDC of 4.4% intelligibility for control speakers, 5.6% intelligibility for speakers with MS, and 11.2% intelligibility for speakers with PD. These estimates are comparable to the MDC previously found for speakers with ALS under similar conditions (i.e., orthographic transcription of SIT sentences in a quiet listening environment, etc.). Calculation of the MDC is the first step to understanding real and relevant change for patients with motor speech disorders. The estimates provided by this project are a step toward the development of a universal language with which to evaluate speech changes in a variety of populations.

Key Words: intelligibility; minimally detectable change; dysarthria

Acoustic Correlates of Intelligibility in Dysarthria: Findings from Between-Speaker Hybridization

van Brenk, F., Kain, A., & Tjaden, K.

We report a study investigating the acoustic basis of intelligibility variation using a speech-analysis resynthesis paradigm termed hybridization (Kain et al., 2008) to blend acoustic properties of sentences produced by male speakers with known differences in baseline intelligibility. Speakers were identified on the basis of previously reported transcription intelligibility scores for Harvard Sentences (Stipancic et al., 2016). Speakers were selected from an existing database to represent a range of intelligibility scores amongst a pool of 28 male speakers. One speaker with PD and a median intelligibility score was identified as the base speaker. Three speakers with PD having the lowest, 25th percentile, 75th percentile intelligibility scores and one neurotypical speaker having the highest intelligibility score were identified as the donor speakers. Using the hybridization paradigm, acoustic properties including the sentence level energy envelope, F0 envelope, segment durations, short-term spectra, were individually or in combination extracted from sentences produced by each donor speaker, and donated to the same sentence produced by the base speaker to form hybrid sentences. Transcription scores of hybrid and original sentences obtained from 520 crowd-sourced

listeners were the primary outcome. Statistical analyses indicated that Spectrum, Duration+Spectrum, and Intonation+Energy+Duration hybrid variants were the strongest predictors of intelligibility variation. Singular acoustic properties of duration, intonation, or energy did not account for intelligibility variation. These results indicate that 1) between-speaker hybridization may produce intelligibility improvements of dysarthric speech, and 2) both segmental and suprasegmental properties of the acoustic signal mediate intelligibility losses associated with dysarthria.

Key Words: between-speaker hybridization; intelligibility; dysarthria

Rate of Decline in Speaking Rate and Intelligibility in Amyotrophic Lateral Sclerosis: A Longitudinal Study

Eshghi, M., Connaghan, K. P., Perry, B. J., Maffei, M., Yunusova, Y., & Green, J. R.

Speech function declines progressively in amyotrophic lateral sclerosis (ALS). Improved prognostic models of speech decline are needed to optimize clinical care and expedite ALS clinical trials. This longitudinal study aimed to 1) model the rate of decline in speech functional measures over the course of ALS, accounting for onset site, sex, and age; and 2) estimate the effect of onset site on the time until speech loss. Participants consisted of 166 individuals with ALS (30 bulbar/136 spinal; 95 males; mean age= 58 years). Measures of speaking rate and intelligibility were extracted from the Sentence Intelligibility Test. Linear mixed effect models revealed significant effect of onset site on the rate of decline in speech functional measures. With the intercept of 166 wpm, the rate of speech declined by 1.31 and 2.50 wpm each month (since symptom onset) in individuals with spinal and bulbar onsets, respectively. Speech intelligibility demonstrated the intercept of 96% and declined by 0.29% and 1.61% each month in individuals with spinal and bulbar onsets, respectively. Kaplan-Meier curves indicated that the median time to speech loss (intelligibility <85%) was 23 and 50 months for individuals with bulbar and spinal onsets, respectively. Additionally, while the median time to exhibiting speaking rate <120 wpm was 23 months for those with bulbar onset, 60% of participants with spinal onset maintained speaking rate >120 wpm over the 60-month follow-up period. These findings inform our understanding of ALS disease progression and will contribute to the literature supporting best practices for timely intervention.

Key Words: Amyotrophic Lateral Sclerosis; speaking rate; speech intelligibility

Voystick: a vocal joystick for vowel production training

Niziolek, C. A. & Comeau, N.

Auditory and somatosensory feedback help to guide speech movements, but learning novel speech production targets can still be a challenge for adult speakers. The current study investigates speakers' ability to use visual feedback to refine vocal movements. Sixteen participants took part in a single-session speech motor learning paradigm in which their spoken acoustics were mapped to a

real-time cursor display. Participants used this "vocal joystick" (Voystick) to move the cursor to visual targets defined in formant frequency (F1-F2) space. Two targets corresponded to native English vowels (/ʔ/, /ow/), with target formants defined by average baseline productions; two targets were novel vowels (/ø/, /ʔ/), defined as linear combinations of formants from the baseline productions. Participants completed 45 trials for each target in a pseudorandom order. Initial data analysis showed that speakers learned over the course of the experiment, reaching targets more often and more quickly, and spending more time in the vicinity of the targets, as defined by the average distance over the course of the trial (all $p < 0.005$). Native and novel vowels did not differ in the percentage of targets reached or time to target, but native vowels achieved a closer average distance to the target by the end of the experiment than novel vowels ($p = 0.002$). This work establishes the capacity of the Voystick system to promote speech motor learning, and has the potential to investigate the formation of vocal motor programs in the absence of auditory feedback.

Key Words: speech motor learning, vowel production, visual feedback

Modeling studies of speech production under delayed auditory feedback

Weerathunge, H. R. & Bohland, J. W.

Delayed auditory feedback (DAF) can have profound impacts on speech motor control, leading to reduced speech rate, increased intensity and fundamental frequency, and an array of fluency errors. Despite extensive research using DAF, the mechanisms that drive speech errors remain poorly understood. Here we report preliminary computational modeling studies that aim to provide a more comprehensive explanation of these effects. Experimental work on paced syllable sequence and sentence productions has identified three challenges to existing models: (1) DAF drives a dominant pattern of vowel and whole syllable repetitions, (2) these errors likely include both sound selection errors (discrete serial order errors) and co-production errors (blends), and (3) speakers' vowel formant productions tend to steer toward the auditory feedback signals. We explain these observed patterns using a simplified version of the GODIVA model, extended to include a perceptual component and coupled sensory and motor oscillators. In this account, delayed, self-generated speech inputs act similarly to externally generated speech, arriving at periods of relatively high auditory cortex excitability (cf. the commonly observed speech-induced suppression). This in turn produces unexpected sensory input, which is hypothesized to drive additional excitation of the corresponding speech planning representations. We demonstrate that, depending on the level at which these sensory-to-motor inputs are received, repetitions of individual sounds or whole syllables can be elicited. Furthermore, if initiation of a (syllable-sized) speech motor program begins before competitive selection of the target is complete, a co-production error will occur, with production biased toward the previous sound / auditory feedback signal.

Key Words: modeling; feedback; sequencing

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Concurrent validity of automatic DDK analysis methods across dysarthria severity in ALS

Tanchip, C., Guarín, D. L., McKinlay, S., Barnett, C., & Yunusova, Y.

Oral dysdiadochokinesis (DDK) is a standard dysarthria assessment task in ALS. Numerous DDK analysis algorithms based on acoustic signal processing are available, including amplitude-based, spectral-based, and hybrid. However, these algorithms were predominantly validated against patients with no perceptible to mild dysarthria [1-5]. The behavior of these algorithms across dysarthria severity is largely unknown. We aimed to fill this gap by studying the performance of five DDK algorithms used in clinical dysarthria assessment as a function of dysarthria severity.
We analyzed 282 DDK recordings of /ba/, /pa/, and /ta/ from 145 participants with ALS. Recordings were stratified into mild, moderate, or severe dysarthria groups based on performance on the Speech Intelligibility Test [6]. Analysis included manual and automatic estimation of the number of syllables, DDK rate, and cycle-to-cycle temporal variability (cTV). Validation metrics included Kendall's tau-b correlations between manual and algorithm-detected DDK rate and cTV, Bland-Altman mixed effects limits of agreement between manual and automatic syllable counts, and recall and precision between manual and automatic syllable boundary detection.
The amplitude-based algorithm (absolute energy) yielded the strongest correlations with manual analysis across all severity groups for DDK rate (?b = 0.84) and cTV (?b = 0.84) and the narrowest limits of agreement (-7.34 to 8.40 syllables). Moreover, the amplitude-based algorithm provided the highest mean recall and precision across severity groups for /ba/ and /pa/. Based on these observations, we concluded that a simple, absolute energy-based algorithm is the most robust tool for DDK analysis across dysarthria severity.

Key Words: dysarthria; DDK; acoustic analysis

Can Listener Training Improve Multidimensional Scaling of Dysarthric Speech?

Threlkeld, K., Golzy, M., & Kuruvilla-Dugdale, M.

Auditory-perceptual methods are an essential part of dysarthria assessment, but rater variability for perceptual judgments is considerably high. Several factors contribute to the low rater reliability estimates such as unequal definitions of perceptual dimensions, unstable internal standards, and varied experience levels among raters. Rater training has been used to improve reliability of voice evaluation by providing listeners with explicit definitions and anchors, along with practice and feedback on rating exercises. This study sought to examine the effects of a Stimulus-Response-Feedback-Stimulus training paradigm on multidimensional dysarthria ratings and on rater reliability and agreement. A training and no-training group, comprising 22 inexperienced listeners each, judged speech intelligibility test (SIT) samples from six speakers each with ALS, PD, and healthy controls, using a visual analog scale (VAS). Both groups initially rated overall severity and severity of three features: imprecision, monotony, and slow rate, with only general instructions from the experimenters. Then, the training group participated in orientation, familiarization, and rating practice exercises with Grandfather Passage samples from the three speaker groups, to evaluate

overall and feature-specific severity. The training group completed post-training ratings of the same SIT samples as pre-training. Preliminary results from generalized liner mixed effects models indicate training effects only for the ALS group, with the training group showing significantly lower VAS scores post-training, but not during pre-training, compared to the no-training group. Statistical analysis to determine training effects on inter- and intra-rater reliability and agreement is ongoing. The clinical utility of the training paradigm and future directions will be discussed.

Key Words: Dysarthria, auditory-perceptual training, visual analog scaling

Functional connectivity in children with residual speech sound disorder

Spencer, C., Vannest, J., Sizemore, E. R., Preston, J. L., Maas, E., McAllister, T., Whalen, D. H., & Boyce, S.

Neural mechanisms in children with residual speech sound disorders (RSSD) have been reported to differ from typical peers, but whether these neural mechanisms change in the context of a therapy program has been understudied. In this study, we examined functional connectivity in children with RSSD during a Syllable Repetition Task before (Time 1) and after (Time 2) a speech therapy program. Methods: Sixteen children with RSSD (6F; ages 8;0-12;6) and 17 children with typically-developing speech (TD; 8F; ages 8;5-13;7) participated in an fMRI experiment using two variations of the Syllable Repetition Task: the SRT-Early Sounds and SRT-Late Sounds. Utilizing a seed-to-voxel analysis, we examined functional connectivity of the left inferior frontal gyrus to the rest of the brain. Additionally, we correlated the connectivity analyses with the progress the children made in therapy.
Results: Significant changes over time in functional connectivity were observed for the RSSD group on the SRT-Early Sounds and SRT-Late Sounds. Significant changes over time were also observed for the TD group on the SRT-Early Sounds, but not on the SRT-Late Sounds. Comparison between the RSSD and TD groups showed an area of difference near the left insula on the SRT-Late Sounds at Time 2. No significant relationship between functional connectivity and severity of the RSSD at baseline or degree of progress in therapy was found.
Discussion: RSSD appears to involve substantial differences in functional connectivity of speech motor networks, both in relation to typical speakers and in relation to undergoing speech therapy.

Key Words: residual speech sound disorder; connectivity; fMRI

The effects of sustained oromotor activity for speech motor performance: Speech biomechanics and neurophysiologic correlates

Stipancic, K. L., Kuo, Y.-L., Miller, A., Ventresca, H. M., Sternad, D., Kimberley, T. J., & Green, J. R.

Sustained limb motor activity has been used as a therapeutic tool for improving rehabilitation outcomes and is thought to be mediated by neuroplastic changes associated with activity-induced cortical excitability. Although prior research has reported enhancing effects of continuous chewing and swallowing activity on learning, the potential beneficial effects of sustained oromotor activity on

speech improvements is not well-documented. This exploratory study was designed to examine the effects of continuous oromotor activity on subsequent speech learning. Twenty neurologically healthy young adults engaged in periods of continuous chewing and speech after which they completed a novel speech motor learning task. The speech motor learning task was designed specifically for this study and involved repetition of eight-syllable nonwords. A control condition was used to estimate baseline improvement rates of speech accuracy and performance during the novel task. In addition, transcranial magnetic stimulation (TMS) was used to measure the cortical silent period (CSP) of the lip motor cortex before and after continuous periods of chewing and speech. All repetitions of the nonword task were recorded acoustically and kinematically using a three-dimensional motion capture system. Productions of the novel nonword were analyzed for accuracy and duration, as well as lip movement distance and speed. Results revealed that the speech learning task elicited improvements in accuracy and efficiency of speech performance across repetitions. Overall, findings suggested that chewing facilitated subsequent speech performance, whereas speech had a detrimental impact on subsequent speech performance. There was no change in the CSP as a result of either oromotor activity.

Key Words: speech motor learning; kinematics; transcranial magnetic stimulation

Stop voicing contrasts along a speech rate continuum in Parkinson's disease

Knowles, T., Adams, S., & Jog, M.

The purpose of this study was to quantify stop voicing distinctiveness in people with Parkinson's disease (PD) along a range of modified speaking rates from very slow to very fast.
People with PD (n = 34) and older healthy controls (n = 17) read aloud sentences from the Sentence Intelligibility Test at their habitual rates of speech, three slower rates, and three faster rates elicited via magnitude production. Speaking rates for each participant were considered proportional to their mean habitual rate in words per minute. Voice onset time (VOT) of word initial, pre-vocalic stop consonants was measured and modelled as a function of speaker group, proportional rate of speech, and stop voicing using linear mixed regression.
Both groups successfully adjusted their rates of speech to similar degrees. Preliminary results suggest that talkers with PD, compared to controls, produced reduced stop voicing contrasts at habitual rates of speech, but successfully increased contrastiveness in very slow speech by lengthening voiceless VOT. At faster relative rates of speech, talkers with PD demonstrated a greater collapse of voicing contrasts due to shorter voiceless VOT. Controls maintained a relative distance between voiced and voiceless VOT (when VOT was expressed on a log scale) while PD talkers did not.
In summary, despite making similar modifications to speaking rates, talkers with PD, compared to controls, produced different magnitudes of temporal adjustments in the release of stop consonants in slow and fast speech. Results carry implications for identifying predictors of candidacy for rate modification treatments.

Key Words: Parkinson's; acoustics; VOT

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Altered Auditory Feedback in Pediatric Populations: A Scoping Review

Coughler, C., Quinn de Launay, K. L., Purcell, D. W., Beal, D. S., & Oram Cardy, J.

Purpose: Auditory feedback has been shown to play a key role in the acquisition and maintenance of fluent speech across speech and language development. Despite this, little is known about the developing speech motor control system throughout childhood, in particular if and how postural and phonemic settings may differ across development. Investigations of individuals' responses to altered auditory feedback provides insight into auditory feedback control and sensorimotor learning. The current scoping review explored how frequency altered auditory feedback has been used in pediatric populations.

Method: Six academic databases were systematically searched for articles that included (a) real-time perturbation of frequency auditory input, (b) an analysis of immediate effects on speech, and (c) pediatric population.

Results: Nineteen articles were retrieved, manipulations included: eight of fundamental frequency, nine of formant frequency, one of frequency centroid of fricatives, and one of both fundamental and formant frequencies. Findings indicated that children above four generally compensated in the opposite direction of the manipulation, however, in several cases not as effectively as adults.

Conclusion: Overall, a wide range of manipulations, findings, and designs were utilized making generalization challenging. Differences in the features of the compensation vocal responses found between age groups imply that maturational changes are occurring in the speech motor control system, affecting the extent to which auditory feedback is used to modify internal motor representations. Varied findings between responses to phonemic and postural manipulations suggest differing developmental trajectories.

Key Words: altered auditory feedback; pediatric

A novel computational model for estimating sensitivity to formant perturbations

Daliri, A.

The speech motor system uses two control systems: feedforward and feedback systems. In the present study, we developed a new state-space model to be able to estimate the error sensitivity of both control systems in an adaptation paradigm. We also conducted an auditory perturbation experiment to examine whether the model's parameters can be used as estimates of the error sensitivity of the control systems. Participants (N=50) completed an adaptation paradigm in which formants of their /?/ were shifted toward their /?/ (an increase in the first formant and a decrease in the second formant). We measured participants' early adaptive responses (within 0–80 ms) and late adaptive responses (within 220–300 ms). As data-driven correlates of the error sensitivity of the feedforward and feedback systems, we used the average early responses and difference responses (i.e., late minus early responses), respectively. As model-based estimates of error sensitivity, we used

parameters of the model fitted to each participant's early and late responses. Our analysis showed that (1) the late responses were larger than the early responses, (2) the model-based estimates of error sensitivity strongly correlated with the data-driven estimates, and (3) the data-driven and model-based estimates of error sensitivity of the feedforward system did not correlate with those of the feedback system. Overall, these results suggested that the state-space model can accurately predict the dynamics of adaptive responses. Additionally, these results suggested that the feedforward and feedback control systems may function independently.

Key Words: Adaptation, Prediction Error, Computational Model

The Role of Rhythm in Conversational Success

Wynn, C., Barrett, T., & Borrie, S.

Purpose: Conversational entrainment is defined as the tendency for individuals to modify their communicative behaviors to more closely align with the behaviors of their conversation partner. Given its role in fostering conversational success, understanding the factors that facilitate entrainment is critical. One potentially crucial but surprisingly overlooked driver of entrainment is rhythm perception ability. Here, we examine the role of rhythm perception in conversational entrainment and subsequent conversational success.

Methods: A novel round-robin paradigm was used to collect 90 conversations from neurotypical adults. Additional measures were used to determine participants' rhythm perception abilities and social competence, and the degree to which conversation partners knew each other prior to the conversation. Mediation analysis was used to examine the relationships between rhythm perception abilities, speech rate entrainment (local synchrony), and a measure of conversational success based on third-party listener observations. Findings were compared to analyses of three additional predictive factors: gender, partner familiarity, and social competence.

Results: Results indicated a significant relationship between rhythm perception ability and conversational entrainment and between conversational entrainment and conversational success. The relationships between conversational entrainment and each of the three comparison factors were nonsignificant.

Conclusion: Better rhythm perception abilities were indicative of increased conversational success mediated by higher levels of conversational entrainment. Knowledge of this relationship provides a framework for considering the mechanism by which rhythm perception deficits impact conversation.

Key Words: rhythm; conversation; entrainment

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Modelling sensorimotor adaptation in speech through alterations to forward and inverse models

Chen, T., Lammert, A., & Parrell, B.

Previous work has shown that sensorimotor adaptation of a particular vowel can be transferred to other, untrained, vowels. Moreover, the magnitude of this transfer decreases as the acoustic distance between the training and the transfer vowels increases. However, current models of speech sensorimotor adaptation which rely on changes in the feedforward control of specific speech units, like DIVA, are unable to account for this type of generalization. In this study, we developed a neural-network based architecture to computationally simulate behavioral results of speech motor learning and transfer, and assess whether updates to internal control models could account for the observed generalization patterns. First, we used the Maeda vocal track simulator to generate pairs of "motor commands" (Maeda parameter vectors) and their corresponding acoustic outcomes (first two vowel formants). Based on this dataset, we trained two independent neural networks: 1) an inverse model, which generates motor commands for desired acoustic outcomes and 2) a forward model, which maps motor commands to acoustic outcomes (prediction). When perturbations were given, both forward and inverse models were updated when there was a mismatch between predicted and perceived output. Our results replicate behavior in previous experiments: the model produced changes in speech production that counteracted the imposed perturbation, and it showed gradient transfer of learning dependent on acoustic distance. These results suggest that updating paired forward and inverse models provides a plausible account for speech motor learning.

Key Words: sensorimotor adaptation, modeling, transfer of learning

Converging Neural Representations of the Speech Subsystems: A Meta-Analysis

Kearney, E., Jiang, L., & Guenther, F.

Background. Speech is a highly complex motor task that relies on precisely coordinated movements across multiple speech subsystems, including respiration, phonation, and articulation. Brain regions with converging representations of the different speech subsystems are thus primary candidates for speech motor control. The goal of the current work was to (1) identify potential regions of convergence for non-speech articulatory movements, and (2) compare these regions to those identified in prior meta-analyses of speech production.

Method. Three databases (PubMed, CINAHL, PsychInfo) were searched in July 2020 to identify neuroimaging studies of non-speech movements. Peak coordinates of task-related activity were extracted and submitted to one of five activation likelihood estimate (ALE) meta-analyses. These analyses were aimed at localizing the neural control of movements of the respiratory musculature, larynx, tongue, lip, and jaw. Regions of high convergence were identified and compared to regions involved in speech production.
Results. Data from 76 fMRI and PET studies from 1991-2020 were included in the analyses. Regions

of high convergence across the five meta-analyses included the rolandic cortex, inferior frontal gyrus, supplementary motor area, cerebellum, basal ganglia, and thalamus. When compared to prior meta-analyses of speech production, each region of convergence had a corresponding region associated with speech production.

Conclusion. With the exception of auditory cortical regions in the superior temporal lobe, brain regions involved in speech motor control overlap extensively with regions involved in non-speech movements of the speech subsystems.

Key Words: speech motor control; fMRI; PET

Voice Acoustics and Vocal Effort in Mask-wearing Healthcare Professionals: A Comparison Pre- and Post-workday

Patel, T. H., Kendall, C. L., & McKenna, V. S.

Purpose: We evaluated how face masks impact voice acoustics and self-perceptual ratings in healthcare professionals. Method: Twenty-one subjects (14 cisgender female, 7 cisgender male; M = 33.38 years), completed self-perceptual ratings and acoustic recordings before and after a typical workday. Chosen measures were specific to vocal effort, dysphonia, and laryngeal tension. Mixed effects models were calculated to determine the impact of session (pre-/post-workday), mask type (N95, simple), sex, and their two-way interactions on the set of perceptual and acoustic measures. Results: The subjects self-reported a significant increase in vocal effort and dyspnea, as well as a significant reduction in vocal quality following the workday. These perceptual changes coincided with a significant increase in vocal intensity and harmonics-to-noise ratio but decrease in relative fundamental frequency (RFF) offset 10. As expected, men and women differed in measures related to fundamental frequency and vocal tract length. There were few significant effects of mask type and few interaction effects. Conclusion: Healthcare professionals required to wear masks reported greater vocal symptoms at the end of the workday. These symptoms coincided with acoustic changes previously related to vocal effort; however, the degree of change was considered mild. Further research is needed to determine how long-term mask use impacts vocal health.

Key Words: voice; effort; acoustics

The Association of Acoustic Measures of Speech Function with Communicative Participation in ALS

Connaghan, K. P., Rowe, H. P., Okada, J., Richburg, B., Berry, J. D., & Green, J. R.

People with amyotrophic lateral sclerosis (PALS) report significant restrictions to their communicative participation – the engagement in "situations in which knowledge, information, ideas, or feelings are exchanged" (Eadie et al., 2006). Although speech motor impairments are likely a major contributor, little is known about which attributes of dysarthric speech are key factors in these restrictions. Yet

this information is essential for prioritizing treatment goals to facilitate communicative participation. The current study was designed to evaluate the contribution of several acoustic speech features to the communicative participation of PALS. Data were collected remotely using the Beiwe smartphone research platform. Twenty-seven PALS (12 female; mean age = 58.5 years) completed the Communicative Participation Item Bank–short form (CPIB), a patient-reported outcome measure of communicative participation. Participants also recorded a battery of speech and non-speech tasks, including syllable repetition, sustained phonation, and passage reading. Acoustic measures indexing function across speech subsystems were extracted from the recordings offline. PALS who self-reported bulbar symptoms had significantly greater communicative participation restrictions than PALS without bulbar involvement ($p<0.001$). Pearson product correlations revealed that the highest associations were between CPIB scores and measures reflecting articulatory impairments, such as articulation rate ($r=.76$, $p<.001$). Multiple linear regression analysis of was conducted to determine the contribution of the acoustic variables to communicative participation restrictions. Speaking rate accounted for the greatest portion (51%) of variability in the CPIB score. The findings highlight the need to address bulbar impairment, with a focus on articulatory function, to support the communicative participation of people with ALS.

Key Words: communicative participation; acoustics; ALS

Neural activity in the frontal cortex during stopping of ongoing speech production

Zhao, L., Silva, A. B., & Chang, E. F.

An important capacity for normal speech production is the ability to stop ongoing production as necessary. Inability to do so is indicative of speech disorders or communication problems. Previous studies have investigated the neural control for canceling speech and other motor outputs before their onset. However, it is largely unknown how, when one has already started speaking, the brain controls speech termination. Here we studied this question by directly recording neural activity from the human frontal cortex while participants start and stop their speech following visual cues. We found increased high-gamma activity near the end of the production in the frontal cortex during cued stopping, which was not observed in self-paced, natural finish of a sentence. Across single trials, a subset of frontal regions was activated according to the time of stop cue or stop action. Activity in single electrodes and across populations distinguish whether stopping occurred before an entire word was finished. In addition, we ask how the neural process for stopping is related to concurrent articulatory control. We found that stop-related activity exists in largely separate regions from those in the sensorimotor cortex encoding articulator movements. Interestingly, there is increased functional connectivity between stop-related and articulator encoding regions during stopping, as compared to speech production before the stop cue. Together, these data suggest that neural activity in frontal cortical regions may underlie the control of stopping ongoing speech production.

Key Words: Motor control, stopping, frontal cortex

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The impact of face masks on speech and voice acoustics in healthcare professionals

Kendall, C. L., Patel, T. H., & McKenna, V. S.

With the onset of the COVID-19 pandemic, healthcare workers are now required to wear face coverings throughout the day. The impact on speech and voice acoustics and the perception of their own vocal abilities has not been fully reported. We enrolled 21 healthcare workers (13 cisgender female, 8 cisgender male; M = 32.9 years) and assessed speech/voice acoustics and self-perceptual measures with and without a mask in place. Measurements included: i) acoustic triangular vowel space, ii) cepstral and spectral acoustic measures; iii) traditional vocal measures of fundamental frequency, intensity, jitter, shimmer, and harmonics-to-noise ratio; iv) relative fundamental frequency (RFF) offset cycle 10 and onset cycle 1, and v) self-reported ratings of vocal effort, vocal quality, and dyspnea. A comparison between mask-on and mask-off conditions showed that when masks are on, there is a significant reduction in vowel space, loss of high-frequency information (cut-off criterion > 4kHz), increase in cepstral peak prominence and its SD, and reduction in RFF offset 10. There was also a significant increase in self-reported vocal effort and dyspnea and reduction in vocal quality when speaking through the mask. Further investigation into mask type (simple mask, N95) and sex (male, female) yielded few significant comparisons. From these data we concluded that masks pose an additional barrier to effective communication and increase the potential for voice strain, effort, and fatigue in healthcare professionals.

Key Words: voice; acoustics; effort

An examination of the relationship between sentence length and speech rate in children with dysarthria

Darling-White, M. & Jaeger, A.

It has been hypothesized that changes in sentence length tax both cognitive-linguistic and speech motor skills. One aspect of speech production that appears to be influenced by sentence length is speech rate. This is likely because articulation rate and pauses, the component parts of speech rate, are heavily influenced by both cognitive-linguistic and speech motor control factors. The purpose of this proposal was to examine the effect of sentence length on speech rate and its component parts, articulation rate and pauses, in children with dysarthria. Given the potential for both cognitive-linguistic deficits as well as speech motor deficits in children with dysarthria, it is likely that sentence length will impact speech rate differently in children with dysarthria than in typically developing children.

Seven children with dysarthria due to cerebral palsy and nine children with dysarthria due to Down syndrome participated in this study. Children with dysarthria were between the ages of 8 and 17 years. Children with dysarthria repeated sentences that varied from two to seven words in length. Dependent variables included speech rate, articulation rate, and proportion of time spent pausing. The effect of sentence length for each dependent variable will be examined and discussed. Patterns of change exhibited by children with dysarthria will also be compared to patterns of change

exhibited by typically developing children published in previous work from this laboratory. Results from this study will provide a more comprehensive understanding of the interaction between cognitive-linguistic and speech motor processes in children with dysarthria.

Key Words: dysarthria; children; speech rate

The relationship between dysphonia and acoustic measures of vocal and articulatory variability in children's speech

Heller Murray, E. & Chao, A.

Voice therapy is the recommended treatment for children with dysphonia, yet current outcomes remain varied. This study examined the relationship between dysphonia and variability in two systems critical for speech, the vocal and articulatory systems. Speech samples were selected from an acoustic database of children with no speech, language, or hearing disorders (Bunton & Story, 2016). Although laryngeal status of these children was unknown, previous work has shown that children without voice disorders can present with mild to moderate dysphonia (Tavares et al., 2011). As the focus of this study was to examine the impact of dysphonia (regardless of a disordered or developmental origin), the relationships between dysphonia severity and vocal and articulatory variability were examined in 48 participants (mean age = 4.7 years, range: 2.4 – 6.8 years, 23 females). The coefficient of variation of fundamental frequency (fo) and first formant frequency (F1) was measured between /i/ productions for each participant. There was a significant negative correlation between F1 variability and dysphonia severity ($r = -0.34$, $p = 0.02$). There was no significant relationship between fo variability and dysphonia severity. However, subsequent analysis of only participants with moderate to severe dysphonia demonstrated a significant correlation between dysphonia severity and fo ($r = -0.47$, $p = 0.04$). We surmise that children with increased dysphonia have increased tension in the vocal and articulatory system, resulting in decreased production variability during speech. This work suggests that understanding changes in both the vocal and articulatory system are important for advancements in pediatric voice therapy.

Key Words: Pediatrics, voice, speech

Generalization as a window to speech motor sequence chunking

Masapollo, M., Zezas, E., Chappell, C., Smith, J., Salazar, N., & Goel, J.

Motor chunking facilitates efficient speech sequencing by combining a series of individual articulator movements affiliated with phonological units into a cohesive representation that is more easily held in memory and rapidly executed. Yet the nature and format of these chunk structures has not been fully explicated. The current study used a motor sequence learning paradigm in which the generalization of performance gains from practicing novel phoneme sequences was used to characterize speech motor sequence chunks. Native English speakers intensively practiced producing

monosyllabic sequences composed of onset and coda consonant clusters that violated native phonotactic constraints, thus making them unfamiliar. During the motor practice phase of the experiment, which spanned two days, we observed that speakers executed the sequences with increasing accuracy. After learning, speakers were tested on the production of transfer sequences that overlapped with the practiced sequences to varying degrees. We found that performance improvements from practicing sequences with illegal clusters partially generalized to novel sequences that contained those clusters, but only if they occurred in the same syllable location (onset or coda) as the learned clusters. Partial generalization was also found for novel sequences that contained practiced rhymes (vowel and following consonants). Practicing the whole syllable, however, resulted in even larger performance gains compared to practicing just the clusters or rhymes. Collectively, these findings provide evidence that, during speech motor sequence learning, sequences of articulatory movements are initially segmented into cluster- and rhyme-sized chunks, but that larger syllable-sized chunks override or are formed in addition to these units.

Key Words: speech motor control; sequence learning; motor chunking

Using Perceptual and Kinematic Measures to Validate an Acoustic-Based Framework of Speech Motor Control

Rowe, H. P., Stipancic, K. L., Lammert, A. C., & Green, J. R.

The goal of this study was to assess the criterion (analytical and clinical) and construct (divergent) validity of a novel acoustic-based framework comprised of five key components of motor control: Coordination, Consistency, Speed, Precision, and Rate. Acoustic and kinematic analyses were performed on audio recordings of 22 participants with amyotrophic lateral sclerosis (ALS) producing syllable sequences during a sequential motion rate (SMR) task. Two licensed speech-language pathologists also rated each participant's SMR on the five articulatory dimensions. Analytical validity and clinical validity were assessed by comparing performance on the acoustic features to clinician ratings of the five components and to kinematic correlates of the features, respectively. Divergent validity of the features in the framework was assessed to determine that they represent distinct articulatory constructs. Results revealed moderate to strong analytical validity for every acoustic feature and moderate to strong clinical validity for all features except Coordination. Results also supported the existence of multiple distinct articulatory constructs in the framework, as evidenced by weak correlations between each pair of acoustic features. This study demonstrated that the acoustic-based framework has potential as an objective, valid, and clinically-useful tool for profiling articulatory deficits in speech motor disorders, specifically in speakers with ALS. The findings also suggest that compared to clinician ratings, instrumental measures may be more sensitive to articulatory motor impairments. With further research, this framework could provide more accurate and reliable characterizations of speech deficits, which may eventually increase clinical confidence in diagnosis and treatment of patients with different articulatory impairment phenotypes.

Key Words: articulation; framework; acoustics

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Corrective response to formant perturbation depends on the perturbation direction

Chao, S.-C., Cincera, K., Gurrala, S., & Daliri, A.

When the speech motor system detects a mismatch between its sensory prediction and the incoming sensory feedback, it generates a corrective motor response to compensate for the effects of the mismatch. In a previous study, we used a formant perturbation technique to generate auditory errors. We showed that the magnitude of the corrective response is dependent on the error magnitude: as the error magnitude increases, the corrective response proportionally decreases. However, it remained unclear whether the magnitude of corrective response depends on the direction of the formant perturbation. In this study (N=15), we developed a paradigm in which formant perturbations were generated by shifting the first and second formants of /ʔ/ (1) toward the formants of /æ/, or (2) toward the outside of the vowel space. The two formant perturbations were orthogonal to maximize the difference between the two perturbations. We measured corrective responses to the formant perturbations for each participant. Our preliminary analysis showed that corrective responses were larger for perturbations that generated a categorical error (/ʔ/ shifted toward /æ/). Additionally, participants did not generate corrective responses to perturbations that shifted formants of /ʔ/ toward the outside of the vowel space. These preliminary results contrast with adaptive responses to formant perturbations toward the outside of the vowel space. These results have important implications for models of speech motor control.

Key Words: corrective response; formant perturbation; feedback

Impairment of Speech Auditory Feedback Error Detection and Motor Correction in Post-Stroke Aphasia

Sangtian, S., Wang, Y., Fridriksson, J., & Behroozmand, R.

The present study investigated how damage to left-hemisphere brain networks in persons with post-stroke aphasia (PWAs) impairs their ability to overtly detect errors in speech auditory feedback. We used the altered auditory feedback (AAF) paradigm to externally induce speech errors by randomly shifting the pitch frequency of the online auditory feedback up or down at ±100 cents in 34 PWAs and 25 neurologically healthy control participants under two experimental conditions: 1) active vocalizations of a steady speech vowel sound “ah,” and 2) passive listening to the playback of the same self-produced vocalizations. Randomized control trials were included between AAF trials where no pitch-shift stimuli were delivered to the auditory feedback during vocalization or listening tasks. Following each vocalization or listening trial, participants pressed a button to indicate whether they heard a change (i.e. error) in their speech auditory feedback (“Yes” or “No”). Analysis of A, a non-parametric measure of sensitivity to signal presence, revealed a significant main effect of group with PWAs performing closer to chance compared to controls in both vocalization and listening conditions. Moreover, we found that speech error detection deficit during listening in PWAs was significantly correlated with their impaired vocal error correction magnitude in response to pitch-shifted auditory feedback during vocalization. Further analyses of behavioral measures and

corresponding EEG signals are forthcoming. These preliminary findings support the idea that overt detection of speech errors in auditory feedback is impaired in PWAs and that damage to left hemisphere brain networks contributes to this impairment.

Key Words: Speech Motor Control; Auditory Feedback; Aphasia

Development of Vocal Biomarkers of COVID-19 Based on Coordination of Speech-Production Subsystems

Talkar, T., Low, D. M., Simpkin, A., Ghosh, S., O'Keeffe, D., & Quatieri, T.

Individuals affected by COVID-19 report a wide variety and range of symptoms, ranging from asymptomatic to severe illness. Particularly, COVID-19 has been shown to present as a dysfunction in respiratory physiology, affecting inhalation and exhalation of air from the lungs. In speech production, there is an inherent coupling between the respiratory system and the laryngeal subsystem during speech production, as well as a coupling between laryngeal activity and articulation. Motivated by our earlier within-subject case study, we hypothesize that we can characterize, detect, and track COVID-19 utilizing measures of neuromotor coordination during speech production. In this pilot analysis, we utilized recordings from a dataset with 17 individuals with a COVID-19 diagnosis who reported as pre- or asymptomatic and 1128 healthy individuals. This open-source dataset, collected by Voca.ai, consists of counting, sustained vowel, and alphabet recitation tasks. From these recordings, we computed the correlations of acoustic time-series such as formants, fundamental frequency, envelope, and mel-frequency cepstral coefficients (MFCCs). These correlations and eigenvalues derived from the correlations act as a proxy for motor coordination across articulatory, laryngeal, and respiratory speech production subsystems. We utilized features derived from these correlations to discriminate between individuals with or without COVID-19 with an area under the receiving operating characteristic curve (AUROC) of about 0.85. In addition, patterns of eigenvalues derived from these correlations suggested a lower complexity of coordination during speech production in individuals with COVID-19. Our initial results indicate the promise of nonintrusive sensing through simple speech recordings for early warning and tracking of COVID-19.

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Key Words: COVID-19, acoustic analysis, motor coordination

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Formant variability is related to vowel duration across speakers

Tang, D-L., Parrell, B., & Niziolek, C. A.

Vowel duration varies systematically as a function of a number of influencing factors (e.g. intrinsic properties, local context, prosodic structure). Recent work has demonstrated that variability of vowel production can be actively controlled as well. However, the relationship between these two remains largely unexplored. The present study investigated the relationship between vowel formant variability and duration by analysing two existing datasets (N=46/25) in which participants repetitively produced monosyllabic words with different vowel sounds under normal feedback. Multiple regression analyses were conducted to determine whether vowel duration differences could be predicted by initial vowel variability (i.e. the average distance in F1/F2 space between each production of a vowel and the center of the distribution for that vowel, measured from the first 50 ms of the vowel) and vowel identity. In both datasets, duration was significantly correlated with initial vowel variability ($p < 0.001$): participants with larger initial variability produced longer vowels. However, the correlation between vowel duration and variability did not hold at the trial level; that is, the duration for a given trial was not predicted by the initial vowel variability of current or previous trials. Together, these results demonstrate that: 1) individuals who are more variable tend to produce longer vowels; 2) but duration is not influenced by initial variability within individuals. As longer durations provide more time to execute feedback-based corrections, these results suggest that individuals who are more variable in general may rely more on feedback-based control for vowel production.

Key Words: vowel duration, initial formant variability, vowel production

Stimulability as a Predictor of Treatment Response in an Ultrasound Biofeedback Study of Rhotic Misarticulation

Eads, A., Kabakoff, H., Boyce, S., Preston, J., Whalen, D. H., & McAllister, T.

Stimulability as originally defined by Milisen (1954) is "a generalized measure of a child's ability to correct errors in an imitative context." Past studies have found a significant relationship between stimulability and response to treatment for speech sound disorders (Miccio 1995, Irwin et al. 1966, Sommers et al 1967). From a speech motor learning perspective, the purpose of pretreatment stimulability assessment is to gauge the level of the participant's phonetic knowledge, while posttreatment assessment gauges whether speech-motor learning occurred during treatment. Volin (1998) found that visual biofeedback training was more effective for participants with poor or moderate stimulability and suggested that biofeedback may be disruptive for highly stimulable participants. Therefore, this study investigates stimulability as a predictor of visual biofeedback treatment response for rhotic misarticulation. As part of a larger examination of the effects of ultrasound biofeedback treatment, 34 American English speakers aged 9-15 with residual /ʔ/ misarticulation were assessed for stimulability before and after treatment using a task adapted from Miccio (2002). In this study, we evaluate stimulability according to acoustically measured accuracy

following Campbell et al. (2017) for fifteen syllable/disyllables of /?/ including prevocalic, postvocalic, and syllabic contexts. Measures of auditory acuity and phonological awareness were obtained at baseline. Stimulability was found to increase over the course of visual biofeedback treatment, but consistent with the findings from Volin (1998), individuals with higher stimulability at baseline showed a smaller average magnitude of change during treatment. Acoustically measured stimulability was significantly correlated with phonological awareness but not auditory acuity.

Key Words: stimulability, /?/ misarticulation, ultrasound biofeedback

The contribution of pitch and loudness control to speech naturalness in ataxia

Cloud, C. & Hilger, A.

The purpose of this study was to analyze the relationship between speech naturalness and motor control of pitch and loudness in ataxia. Ataxia is a clinical sign that occurs in a cluster of heterogenous, debilitating neurodegenerative diseases as a result of damage to the cerebellum and/or its pathways (Manto & Marmolino, 2009), and has been shown to impact coordination and timing in speech (Ackermann & Hertrich, 1994). We hypothesize that damage to the cerebellum impacts pitch and loudness production and control, which contribute to prosodic impairments and reduced speech naturalness in ataxic dysarthria. To test this hypothesis, we are analyzing the variability of pitch and loudness production in 27 individuals with cerebellar ataxia and 29 age- and sex-matched control participants. We will compare the results of this analysis with speech naturalness scores for all participants. We expect that individuals with reduced speech naturalness will have more variability in their pitch and loudness production compared to speakers with relatively preserved speech naturalness and control speakers. If these results are true, then they would demonstrate that pitch and loudness control contribute to reduced speech naturalness in individuals with ataxia. The results of this study are expected to deepen our understanding of motor speech production in ataxic dysarthria and may have broader implications for the treatment of prosodic impairments and speech naturalness in ataxia. If pitch and loudness control significantly contribute to speech naturalness, then speech therapy that targets consistent production of pitch and loudness may result in enhanced speech naturalness.

Key Words: ataxia; prosody; naturalness

Investigating the reliability of computer vision-based orofacial motor assessment

Simmatis, L. E. R., Marzouquah, R., Taati, B., Boulos, M., & Yunusova, Y.

Background: Clinical assessment of speech-related orofacial movement typically relies on subjective impressions made by clinicians. Advances in computer vision have enabled new approaches to quantifying orofacial motor functions, including via remote assessment from patients' homes. However, the reliability of remotely-collected orofacial kinematics is presently unclear.

Methods: Eleven individuals completed a series of video-based orofacial assessments in a laboratory setting using a high-performance camera (Intel SR300), and thirteen completed assessments at home using a custom data collection app on a mobile device (Samsung Tab A7). Facial landmarks were detected in recorded videos using a deep neural network. Movement repetitions were automatically detected using a peak-finding algorithm, and lower lip kinematics (velocity, range of motion, and movement laterality) were quantified. Within-test consistency, test-retest reliability, and individual differences in kinematics over time were estimated using Cronbach's alpha (?), intraclass correlation (ICC), and linear mixed-effects regression (LME), respectively.
Results: Kinematics were reliable within-assessment (? typically >0.80) and across assessments (ICCs often >0.60) for both SR300 and A7 data. Including individual random effects in the LME provided a significantly better fit to the data than either 1) fixed effect of time only, or 2) fixed effect of time plus random intercept (both $p<1.0e-2$), suggesting that our approach could reliably quantify individual longitudinal trajectories.
Conclusion: Our results indicate that objective orofacial kinematics can be measured reliably over time, and that these metrics can capture individual differences in orofacial motor function. This will inform future automated detection and assessment techniques for neurological impairments via orofacial motor assessment.

Key Words: Articulatory kinematics; reliability; deep learning

Effectiveness of Visual-Acoustic Biofeedback in the Remediation of the Phoneme /r/

Peterson, Campbell, Simpson, & McAllister

A reliable treatment method that successfully remediates /r/ errors in all children and adolescents is elusive. Speech-language pathologists (SLPs), who responded to Ruscello's (1995) survey, conveyed the need for more effective treatment approaches to address the challenge of remediating residual speech sound errors, particularly /r/. In response to the appeal for innovative treatment, the present paper will investigate the remediation of /r/ and / ?, ?/ in individuals with residual speech sound errors, with a specific focus on treatment using visual-acoustic biofeedback versus traditional treatment using the Speech Therapist's App for /r/ Treatment (staRt).
All intervention utilized the Speech Therapist's App for /r/ Treatment (staRt) in a single-case randomization design where participants received an equal number of biofeedback and non-biofeedback treatment sessions in a randomized order (McAllister, 2019). The principal investigator (PI) provided intervention to four children, between 9 and ten years of age, with a residual speech sound error impacting /r/.
The first question assessed effect sizes measuring the variation in accuracy from the pre-treatment baseline to the post-treatment maintenance phase, representing participants' response to the overall treatment package. This response surpassed the smallest value to be considered clinically significant in all four participants. The second question used measures of short-term change to compare biofeedback versus traditional treatment conditions. One participant exhibited significantly larger

gains in biofeedback than traditional treatment. No other participant showed a substantial difference between visual-acoustic biofeedback and traditional treatment.

Key Words: biofeedback treatment, residual speech sound errors, traditional intervention, response

Vocal convergence effects during choral speech

Bradshaw, A. R. & McGettigan, C.

Self-generated speech auditory feedback is well known to affect speech motor control; however, there is increasing evidence that perception of external speech inputs may also have effects on a speaker's production of speech sounds. We investigated this idea in the context of choral speech, the act of speaking in synchrony with another speaker. In an online experiment, 20 female participants spoke sentences first alone (solo reading baseline), and then in synchrony with videos of another speaker (accompanist) that were either silent (visual choral speech) or also included audio i.e. the voice of that speaker (visual+audio choral speech) in a between-subjects design. Convergence in F0 was measured as the difference in distance between the participant's F0 and that of the accompanist voice during solo reading versus choral speech. LMM analysis with this measure found an overall reduced F0 distance during choral speech compared to solo reading across conditions; however, critically an interaction was found between phase and condition such that the change in F0 distance between solo reading and choral speech was greater in the visual+audio choral speech condition compared to the visual choral speech condition. At the individual level, 8/10 participants in the visual+audio condition showed significant convergence to the accompanist voice, compared to only 1/10 in the visual-only condition. This provides evidence that phonetic convergence occurs during choral speech; further, these convergent changes in F0 rely on exposure to the other speaker's voice, and are not merely the result of synchronisation with an external stimulus.

Key Words: Phonetic convergence; Choral speech

Voice focus adjustments can lower nasalance scores in some speakers with hypernasality

Bressmann, T., Cuglietta, L., & Santoni, C.

The study explored immediate effects of voice focus adjustments on the nasalance scores of speakers with hypernasality. Three children with cleft palate and hypernasal speech were taught to speak with extreme forward and backward voice focus. Nasalance scores for oral, nasal, and phonetically balanced stimuli were collected with the Nasometer 6450. From the baseline of 39% for the oral stimulus, average nasalance increased to 41% in forward and decreased to 29% in backward focus. From the baseline of 70% for the nasal stimulus, average nasalance decreased to 46% in forward and to 68% in backward focus. From the average baseline of 56% for the phonetically balanced stimulus, nasalance stayed at 56% in forward and decreased to 40% in backward focus. Overall, backward voice focus resulted in lower nasalance scores, which could be explained by lower

impedance of the oral cavity. Conversely, forward focus tended to result in higher nasalance scores in most speakers. However, speaker 3 showed a 22% drop in nasalance for the oral stimulus in the forward focus. Since this could not be explained by lower oral impedance, the drop in nasalance may have resulted from improved velopharyngeal closure instead. Future research should investigate to what extent voice focus can affect the function of the velopharyngeal sphincter in individual speakers.

Key Words: Nasality; Nasalance; Voice focus

Effects of Physiological Arousal on Speech Motor Control in Preschool-age Children with Stutter

Tumanova, V., Bliss, E.

We investigated the influence of preschool-age children's emotional processes on their speech motor practice effects. Methods include assessment of speech motor coordination and autonomic nervous system activity in response to emotionally arousing and neutral stimuli.
Participants were 18 preschool-age (3:0 to 5:11 years:months) children who stutter (CWS) and 20 typically fluent peers (CWNS). The participants repeated a target phrase "Buy Bobby a puppy" (e.g., Smith & Zelaznik, 2004) interspersed with viewing pictures from the International Affective Picture System (IAPS; Lang, Bradley & Cuthbert, 2005) under two experimental conditions: speaking after viewing pictures with (1) negative, and (2) neutral valence. Participants' lip movements were tracked using the Optotrak system. Speech motor practice effects were assessed by examining decreases in speech motor variability over 15 repetitions of the target phrase within a trial and between two trials. The results indicated that CWS had higher speech variability overall compared to CWNS. The negative picture viewing condition was associated with higher speech variability than the neutral picture viewing condition for both groups. Both CWS and CWNS decreased their speech variability from 1st to 2nd trial, indicating that both groups benefitted from speech motor practice. Implications of these findings will be discussed.

Key Words: stuttering, preschool-age children, speech motor control, speech motor practice effects, physiological arousal