Improving children's ultrasound-based lingual complexity measures by quantifying midsagittal alignment

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Background: Broad generalizations can be made about the order in which speech sounds are added to a child's phonemic inventory and typical ways that child speech deviates from adult targets in a given language (Smit et al., 1990). Developmental speech patterns are presumed to reflect differences in both phonological knowledge and the capacity for skilled motor control of speech structures. Specifically, in early stages of development (Green et al., 2000), as well as in disordered speech (Fletcher, 1989; Gibbon, 1999), a reduced capacity to isolate control of anterior versus posterior lingual regions may play a role in children's non-adult-like speech patterns. This ability for different regions of the tongue to operate semi-independently is referred to as "lingual differentiation." Gestures that lack a typical degree of lingual differentiation may be described as "undifferentiated" (Gibbon, 1999). Degree of lingual differentiation for complex targets increases with age (Fletcher, 1989), and thus lingual complexity is believed to reflect an individual's capacity for skilled motor control of the tongue. However, the relative contribution of motor control versus perceptual and phonological factors in developmental and disordered speech patterns remains unknown.

Methods: This study explored links between lingual complexity and phonemic development using ultrasound imaging (USI) of 25 children producing various phonemes, including both typically developing (TD) children and children with speech sound disorder (SSD). The focus was on /ɹ/ due to its late mastery (Smit et al., 1990) and complex lingual shape (Delattre & Freeman, 1968). (See Table 1) A Siemens Acuson X300 ultrasound device

Classification /Gender (N)	Age range	% correct /ɹ/ productions for each child
SSD/F (2)	4;0-5;0	11,100*
SSD/M (6)	4;0-5;11	0,17,43,62,67,71
TD/F (11)	4;3-6;0	0,0,13,33,36,50,75,77,91,100,100
TD/M (6)	4;2-6;3	20,32,62,77,80,100

Table 1: *Summary of current participants, Percentage accuracy for /ɹ/ production reflects developmentally appropriate errors. *Note that 100% /ɹ/ accuracy in SSD indicates that errors were on other targets*

with a Siemens C8-5 transducer was used to record live video through an AverMedia video capture card to a PC. Tongue shapes from a representative USI frame nearest the midpoint of acoustically-defined target intervals were traced using GetContours (Tiede, 2016) in MATLAB (MathWorks Inc., 2000). We quantified midsagittal ultrasound probe alignment in the target frames using MATLAB to track the position of blue dots placed along the vertical midline of the child's face and the probe from frontal video recorded concurrently during USI and temporally aligned using cross-correlation of their mutual audio. See Figure 1 for a visual depiction of blue dot placement and of traced ultrasound images. Video frames with more than 12 mm of lateral displacement or 12° of angular displacement were flagged for further inspection. Figure 2 shows lateral displacement for one child's target frames (red dots) relative to all frames (blue dots), illustrating how outliers appear outside the threshold (red line). For 3 children to date, 11.5% of frames were discarded due to lateral misalignment (5/174) or angular misalignment (15/174).

Results and discussion: We anticipate that TD children will show greater lingual complexity than children with SSD, especially among later developing phonemes. Additionally, we predict that there will be higher lingual complexity in TD children's correct versus incorrect productions. Finally, we believe that results from children with SSD will suggest that lingual complexity may also be correlated with perceptual accuracy in this population. But it is important to ensure that observed complexity is not an artifact of probe misalignment, and the outlier-exclusion procedure described here is a step in that direction. Quantification of lingual complexity in child speech is a key prerequisite for understanding the relative importance of motor factors in children's non-adult-like speech patterns, and may help steer treatment decisions for children with SSD.

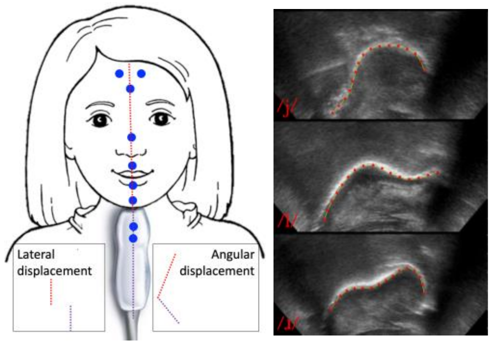

Figure 1: (Left) Blue dot placement on child's face and on ultrasound probe, illustrating how lateral displacement and angular displacement are defined; (Right) Tagged lingual contours for three target phonemes.

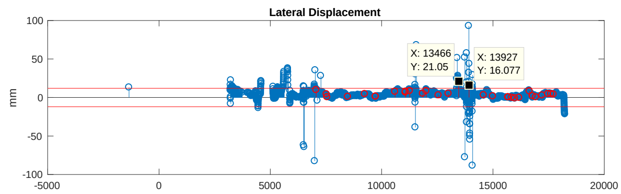

Figure 2: *Lateral displacement values for each frame of video for one child, illustrating how two outliers are identified.*

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