

| Measure  | Description  | Independent of head movement | Example use   |
|--|--|------------------------------|---|
| T-test function<br>(Articulate Instruments Ltd)                      | Determines whether there is a statistically significant difference between two sets of tongue curves along a fan-line.   | No                           | Identification of covert contrast in children with persistent velar fronting (Cleland et al., 2017)         |
| Mean Nearest Neighbour Difference<br>(Zharkova & Hewlett, 2009)      | Quantifies the difference between two tongue curves  | No                           | Coarticulation and stability in people who stutter (Belmont, 2015)  |
| Dorsum Excursion Index DEI<br>(Zharkova, 2013)                       | quantifies the extent of excursion of the tongue dorsum, conceptually represented by the point on the tongue curve located opposite the middle of the straight line between two curve ends | Yes                          | Identification of covert contrast in velar fronting (McAllister Byun et al., 2016)                          |
| LOC <sub>a-i</sub><br>(Zharkova, 2015)                               | Quantifies excursion of the tongue in relation to the back of the tongue.  | Yes                          | Covert contrast of s and ʃ (both stopped to dental) (Zharkova et al., 2017)                                 |
| Curvature Degree<br><br>Curvature position<br>(Aubin & Menard, 2006) | Quantifies the extent of maximal excursion within a single tongue shape<br>Determines where on the tongue curve the excursion is   | Yes                          | Covert contrast of s and ʃ (Zharkova et al., 2017)  |
| Procrustes analysis<br>(Dawson et al., 2016)                         | Gives the sum of the squared differences between two tongue shapes, following translation, rotation, and scaling   | Yes                          | Tongue complexity in vowel production in speakers with Down Syndrome compared to resting state (Carl, 2018) |
| Modified Curvature Index<br>(Dawson et al., 2016)                    | Quantifies curvature degree and number of inflections in a tongue shape  | Yes                          | Tongue complexity in vowel production in speakers with Down Syndrome (Carl, 2018)                           |
| Discrete fourier transformation<br>(Dawson et al., 2016)             | Differentiation of tongue shapes between targets   | Yes                          | Differentiation of tongue shapes for target vowels in speakers with Down syndrome (Carl, 2018)              |
| NINFL Number of Inflections<br>(Preston et al., 2019)                | Count of the number of tongue curvature changes in a single tongue contour   | Yes                          | Tongue complexity in rhotic distortions (Preston et al., 2019)  |
| Peak Velocity<br>(Heyde et al., 2015)                                | Calculates displacement and velocity of tongue movement along a single measurement vector  | No                           | Kinematic analysis in people who stutter (Heyde et al., 2015)   |

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| KT Crescent<br>(Scobbie & Cleland, 2017)                          | Quantifies dorsal velar constriction spatially in relation to a same-speaker alveolar baseline               | Yes | Degree of separation between /k/ and /t/ in a child with persistent velar fronting<br>(Cleland & Scobbie, 2018) |
| Anteriority index<br>3D Ultrasound<br><br>(Bressmann et al. 2005) | Volumetric index indicating relative position of the main mass of intrinsic tongue tissue in the oral cavity | No  | Tongue protrusion following partial glossectomy<br><br>(Bressmann et al. 2005)                                  |
| Concavity index<br>3D Ultrasound<br><br>(Bressmann et al. 2005)   | Measures how convex or concave the shape of the tongue is along the whole length of the tongue volume        | No  | Tongue grooving following partial glossectomy<br><br>(Bressmann et al. 2005)                                    |
| Asymmetry index.<br>3D Ultrasound<br><br>(Bressmann et al. 2005)  | Volumetric measure of the difference in lateral tongue height between each side of the tongue                | No  | Tongue symmetry following partial glossectomy<br><br>(Bressmann et al. 2005)                                    |
| Tongue Displacement<br><br>Bressmann et al., 20116                | Cumulative displacement of maximum tongue height measured radially   | No  | Tongue displacement during production of /r/ before and after intervention<br><br>(Bressmann et al., 2016)      |

Articulate Instruments Ltd 2012. *Articulate Assistant Advanced User Guide: Version 2.14*. Edinburgh, UK: Articulate Instruments Ltd.

Aubin, J., & Ménard, L. (2006). Compensation for a labial perturbation: An acoustic and articulatory study of child and adult French speakers. In H. C. Yehia, D. Demolin, & R. Laboissière (Eds.), *Proceedings of the 7th international seminar on speech production* (pp. 209–216), Ubatuba, Brazil.

Bressmann, T., Harper, S., Zhylich, I., & Kulkarni, G. V. (2016). Perceptual, durational and tongue displacement measures following articulation therapy for rhotic sound errors. *Clinical linguistics & phonetics*, 30(3-5), 345-362.

Bressmann, T., Thind, P., Uy, C., Bollig, C., Gilbert, R. W., & Irish, J. C. (2005). Quantitative three-dimensional ultrasound analysis of tongue protrusion, grooving and symmetry: Data from 12 normal speakers and a partial glossectomee. *Clinical Linguistics & Phonetics*, 19(6-7), 573-588.

Carl, M. (2018). *Vowel Production in Down Syndrome: An Ultrasound Study*. (Unpublished doctoral dissertation). City University New York, New York

Cleland, J., & Scobbie, J. M. (2018). Acquisition of new speech motor plans via articulatory visual biofeedback. *Fuchs, S., Cleland, J., and Rochet-Cappelan, A. (Eds.). Speech Perception and Production: Learning and Memory.*

Cleland, J., Scobbie, J. M., Heyde, C., Roxburgh, Z., & Wrench, A. A. (2017). Covert contrast and covert errors in persistent velar fronting. *Clinical linguistics & phonetics, 31*(1), 35-55.

Cleland, J., Scobbie, J. M., & Wrench, A. A. (2015). Using ultrasound visual biofeedback to treat persistent primary speech sound disorders. *Clinical linguistics & phonetics, 29*(8-10), 575-597.

Dawson, K. M., Tiede, M. K., & Whalen, D. H. (2016). Methods for quantifying tongue shape and complexity using ultrasound imaging. *Clinical linguistics & phonetics, 30*(3-5), 328-344.

Heyde, C. J., Scobbie, J. M., Lickley, R., & Drake, E. K. (2016). How fluent is the fluent speech of people who stutter? A new approach to measuring kinematics with ultrasound. *Clinical linguistics & phonetics, 30*(3-5), 292-312.

McAllister Byun, T., Buchwald, A., & Mizoguchi, A. (2016). Covert contrast in velar fronting: An acoustic and ultrasound study. *Clinical linguistics & phonetics, 30*(3-5), 249-276.

Preston, J. L., McCabe, P., Tiede, M., & Whalen, D. H. (2019). Tongue shapes for rhotics in school-age children with and without residual speech errors. *Clinical linguistics & phonetics, 33*(4), 334-348.

Scobbie, J. M., & Cleland, J. (2017). Area and radius based mid-sagittal measurements of comparative velarity. *Ultrafest VIII, Potsdam, Germany.*

Zharkova, N. (2013). A normative-speaker validation study of two indices developed to quantify tongue dorsum activity from midsagittal tongue shapes. *Clinical Linguistics & Phonetics, 27*(6-7), 484-496.

Zharkova, N., Gibbon, F. E., & Lee, A. (2017). Using ultrasound tongue imaging to identify covert contrasts in children's speech. *Clinical linguistics & phonetics, 31*(1), 21-34

Zharkova, N., & Hewlett, N. (2009). Measuring lingual coarticulation from midsagittal tongue contours: Description and example calculations using English /t/ and /a/. *Journal of Phonetics, 37*(2), 248-256.