FUNCTIONAL DATA ANALYSIS OF LIP MOVEMENTS: REPETITION VARIABILITY AS A FUNCTION OF AGE

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ABSTRACT

This study examined inter-repetition variability of lip movements across repetitions of the same utterance as a function of age in Swedish speakers. Lip movement data of 15-20 repetitions of a short Swedish phrase from 37 typically developed Swedish children and adults (19 females, 18 males, aged 5-31 years) were collected using three-dimensional articulography, and submitted to functional data analysis (FDA), a method for analysing variability in signals. For comparison, we also calculated another metric of variability; the spatiotemporal index (STI). Results showed moderate negative correlations between age and STI as well as the two FDA indices amplitude variability and phase (temporal) variability. Linear regression analysis indicated the largest effect for amplitude variability, and the smallest for phase variability, supporting the potential for factoring out different types of variability for kinetic measurements of lip movements.

Keywords: lip movement variability, articulography, Functional Data Analysis (FDA)

1. INTRODUCTION

This study examined repetition variability of lip movements as a function of age in Swedish speakers. A number of studies, using acoustic analysis e.g., [4, 5, 15] and movement recordings e.g., [12, 16, 17], have shown that variability decreases with age until adolescence. The purpose of the present study was to apply functional data analysis [FDA 10]) to lip movements. Our aim was to extend earlier findings of decreasing variability with age to see if both amplitude and phase change together, or only one of them. Previous studies [3, 11, 13] have used the spatiotemporal index [STI, 14], which only provides a single metric of variability cf. [8], incorporating both amplitude and phase. Koenig, et al. [6] applied FDA to fricative productions in three different age groups and found decreasing variability with age, but also

that temporal variability was less adult-like than amplitude variability. Our long-term objective is to examine (1) if children with atypical language development differ from typically developing children in terms of articulatory variability and (2) the possible relationship with cerebellar function as assessed by the blink reflex.

1.1. Experiment

Movements of the upper and lower lips were recorded along with a microphone signal using the Carstens Articulograph AG500. To obtain as large lip movements as possible, the phrase *Mamma pappa barn* (Mummy daddy children) was selected as speech material. While this phrase superficially may appear as just three words stringed together, it does constitute a meaningful unit in Swedish; it is the Swedish name of the childrens' game 'Play house'. It is also short and can be spoken on a single breath. Sensors were placed on the upper and lower lip. We corrected for head movements by attaching additional sensors on the nose bridge and behind the right ear. Lip movement data of 15-20 repetitions from 37 typically developed Swedish children and adults (19 females, 18 males, aged 5-31 years) were collected. Figure 1 shows the experimental set-up with one subject placed inside the articulograph as well as the positions of the four sensors that were used in the study.

1.2. Pre-processing and landmark registration

Euclidean distances between the upper and lower lip sensors in three dimensions were calculated from the lip movement data, low-pass filtered at 25 Hz and used in the landmark registration. We delimited each token at consistent kinematic events using the first derivative of the distance function and located two points. To obtain four full cycles of opening-closing gestures of the lips, we set the onset point to the maximum velocity of the distance function in the opening phase during the transition from the first *m* to the first *a* in the word

Mamma. For the offset point we used the same transition from the *b* to the *a* in the word *barn*. In determining these points, we thus relied on kinematic information only. An example of the landmark registration procedure environment is shown in Figure 2. Tokens with measurement errors or artefacts were excluded from further analysis.

Figure 1: Experimental set-up with subject placed in the articulograph (top), and a schematic view (bottom) of the sensor positions used in the study: (1) upper lip midsaggital on the vermilion border (2) lower lip midsaggital on the vermilion border (3) reference sensor on the nose bridge, (4) reference sensor behind right ear.
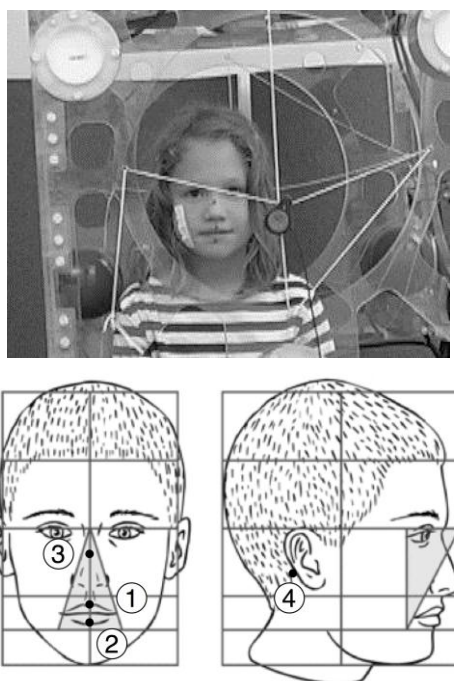

1.3. Functional Data Analysis (FDA) and Spatiotemporal Index (STI)

The landmark delimited Euclidean distance functions were used as input to the FDA and STI, which were then calculated using a MATLAB script developed by J. Lucero. FDA is a technique for time-warping and aligning a set of signals to examine differences between them. Ramsay, et al. [10] first introduced FDA techniques and applications to speech analysis, and these were further developed by Lucero, et al. [8], and Lucero and Löfqvist [7]. The procedure involves the following steps: (1) temporal normalisation of the signals from a number of tokens, (2) calculation of the mean signal, (3) alignment of individual signals to the mean signal using nonlinear time-warping, and (4) computation of one index of

amplitude variability and one of phase (temporal) variability. Each token was amplitude normalised by subtracting its mean and dividing by its standard deviation (SD) [6]. The spatiotemporal index [STI, 14] was also calculated. It provides a single metric of variability cf. [8], incorporating both amplitude and phase. The calculation of STI involves the following steps: (1) amplitude normalisation of each token by subtracting its mean and dividing by its SD, (2) temporal normalisation of each token to 1000 samples through linear interpolation, (3) segmentation of these 1000 samples into 50 bins of twenty samples each (2% intervals), (4) computation of SD across the normalised tokens for each bin. STI is calculated as the sum of the 50 SDs.

Figure 2: Lip distance function (top), its first derivative with marked velocity peaks (middle) and resulting trimmed portion (bottom) of a token during kinematic landmark registration. The vertical lines indicate the positions of the start and end boundaries.
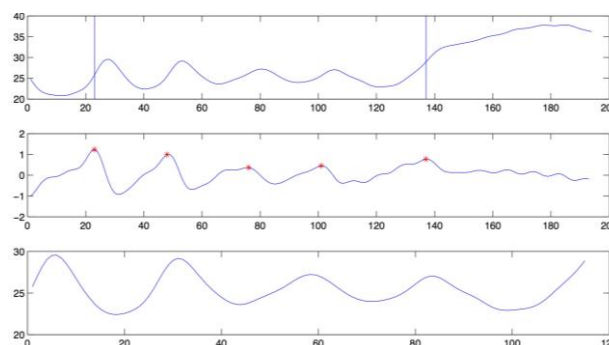

2. RESULTS

To analyse the relationship between age and the FDA indices and STI, we ran correlations and fitted simple linear regression models to the data. We used the means of the standard deviations resulting from the FDA analysis. Figure 3 shows the amplitude variability index (ampV), the phase (temporal) variability index (phaseV), and the spatiotemporal index (STI) as a function of age. Numerical results are summarised in Table 1. Although we have indicated the gender of each subject in the figure, we did not analyse this factor further.

Table 1: Numerical results of amplitude variability index (ampV), phase variability index (phaseV) and STI as a function of age for kinematic landmarks.

	AmpV	PhaseV	STI
Correlation (r)	-0.66	-0.45	-0.63
Marginal effect	-3.4	-0.12	-3.5
Significance	***	**	***
R^2	0.43	0.20	0.40

Figure 3: The relationship between the three variability indices used in the study and age (sample size = 37). Scatter plots and lines of best fit obtained using the R statistical environment [9] (solid line: best fit, dotted lines: prediction intervals, dashed lines: confidence intervals).
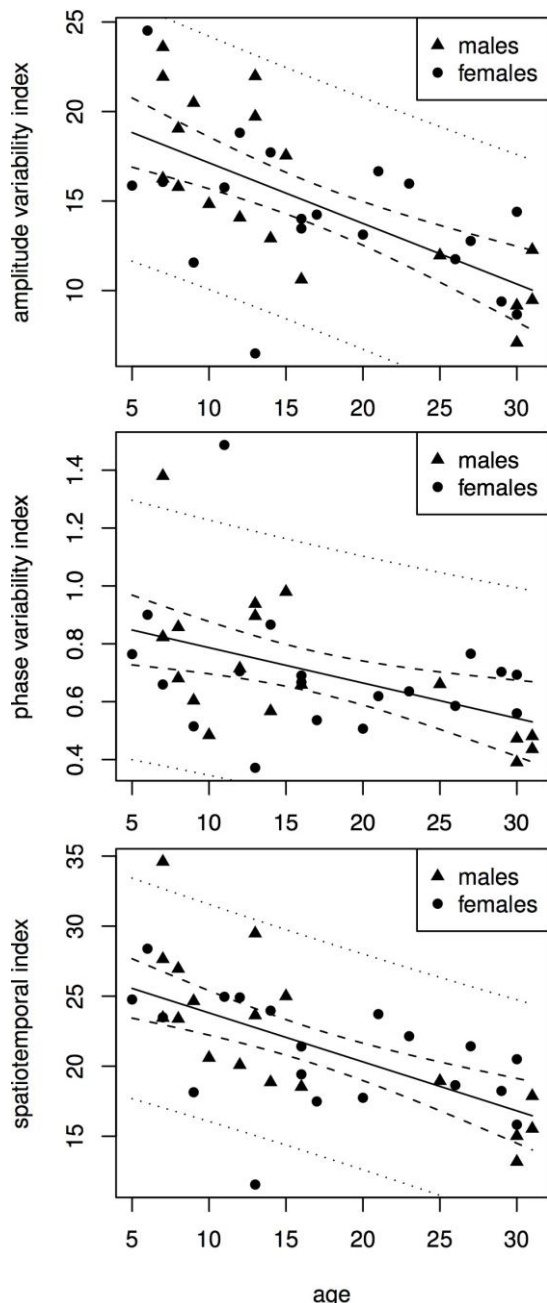
The correlation coefficients (ampV: -0.66, phaseV: -0.45, STI: -0.63) indicated moderate relationships for all indices. A general decrease with advancing age was observed in the lines of best fit for all indices. The marginal effect describes the expected change in an index value associated with a specific change in age. Table 1 shows the expected index value change for an age increase of 10 years. Such an age increase lowers the expected ampV index by 0.34, the expected phaseV index by 0.12, and the expected STI by 3.5. The estimated gradients correspond to age elasticities at the sample mean of -0.43, -0.20 and -0.40, respectively. This means that if the age increases by 1%, the respective index is expected to decrease by 0.43%, 0.20% and 0.40%. The effects were statistically significant for all indices.

3. DISCUSSION AND FUTURE WORK

The results for amplitude variability confirm the results of previous studies, i.e. that lip movement inter-repetition variability decreases with age. However, for phase (temporal) variability, the negative correlation was weaker. Koenig, et al. [6] reported the opposite pattern, with more variability for time than amplitude. Those results were, however, based on records of airflow during fricative production, thus reflecting both articulatory and expiratory factors. The current results are based on articulatory movements alone.

Similar developmental changes have been observed in non-speech motor activities such as reaching and finger tapping [1, 2].

The decrease of repetition variability with age is most likely due to a combination of factors. One factor may be cerebral and cerebellar development [4]. Another one is practice, which leads to more stable motor performance. It is also likely that a developing and changing system will show increased motor variability during transitions, when a new mode of organisation is replacing an old one [18].

In our study, the linear regression analysis indicated a much larger effect for ampV than for phaseV. This seems to support that the separation of different types of variability is useful when analysing measurements of articulatory lip movements.

In further studies, we intend to record not only more typically developed children, but also atypically developed children. Future work also includes experiments to see if children with atypical language development differ from typically developing children in terms of articulatory variability. We also want to examine the possible relationship of our results with cerebellar function as assessed by the blink reflex.

4. ACKNOWLEDGEMENTS

5. REFERENCES

[1] Deutsch, K.M., Newell, K.M. 2003. Deterministic and stochastic processes in children's isometric force variability. *Dev. Psychobiol.* 43, 335-345.

[2] Deutsch, K.M., Newell, K.M. 2004 Changes in the structure of children's isometric force variability with practice. *J. Exp. Child Psychol.* 88, 319-333.

[3] Goffman, L., Smith, A. 1999. Development and phonetic differentiation of speech movement patterns. *J. Exp. Psychol.: Hum. Percept. Perform.* 25, 649-660.

[4] Kent, R. 1976. Anatomical and neuromuscular maturation of the speech mechanism: Evidence from acoustic studies. *J. Speech Hear. Res.* 19, 421-427.

[5] Kent, R., Forner, L. 1980. Speech segment duration in sentence recitation by children and adults. *J. Phonetics* 8, 157-168.

[6] Koenig, L., Lucero, J., Perlman, E. 2008. Speech production variability in fricatives of children and adults: Results of functional data analysis. *J. Acoust. Soc. Am.* 124, 3158-3170.

[7] Lucero, J., Löfqvist, A. 2005. Measures of articulatory variability in VCV sequence. *Acoust. Res. Lett. Online* 6, 80-84.

[8] Lucero, J., Munhall, K., Gracco, V., Ramsay, J. 1997. On the registration of time and the patterning of speech movements. *J. Speech Lang. Hear Res.* 40, 1111-1117.

[9] R Development Core Team. 2011. *R: A Language and Environment for Statistical Computing.* Webpage: *http://www.R-project.org.*

[10] Ramsay J.O., Munhall K.G., Gracco V.L., Ostry D.J. 1996. Functional data analysis of lip motion. *J. Acoust Soc. Am.* 99, 3718-3727.

[11] Sadagopan, N., Smith, A. 2008. Developmental changes in the effects of utterance length and complexity on speech movement variability. *J. Speech, Lang. Hear. Res.* 51, 1138-1151.

[12] Sharkey, S.G., Folkins, J.W. 1985. Variability in lip and jaw movements in children and adults: Implications for the development for speech motor control. *J. Speech Hear. Res.* 28, 8-15.

[13] Smith, A., Goffman, L. 1998. Stability and patterning of speech movement sequences in children and adults. *J. Speech Lang. Hear. Res.* 41, 18-30.

[14] Smith, A., Goffman, L., Zelaznik, H.N., Ying, G., McGillem, C. 1995. Spatiotemporal stability and patterning of speech movement sequences. *Exp. Brain Res.* 104, 439-501.

[15] Smith, B.L. 1978. Temporal aspects of English speech production: A developmental perspective. *J. Phonetics* 6, 37-67.

[16] Smith, B.L. 1995. Variability of lip and jaw movements in the speech of children and adults. *Phonetica* 52, 307-316.

[17] Smith, B.L, McLean-Muse, A. 1986. Articulatory movement characteristics of labial consonant productions by children and adults. *J. Acoust. Soc. Am.* 80, 1321-1328.

[18] Smith, L., Thelen, E. 2003. Development as a dynamical system. *Trends Cog. Sci.* 7, 343-348.