DIAGNOSTIC VALUE OF ARTICULATION NEUROMOTOR INSTABILITY FOR NEURODEGENERATIVE DISEASE DETECTION AND RATING

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INTRODUCTION

Neurodegenerative diseases leave an imprint on both phonation and articulation stability. Hypotonia (muscle stiffness), vocal fold unbalance (bi-laterality) and tremor (altered neuromotor feedback) some ways in which the degeneration manifests. Articulatory instability has been less studied, compared to reduced vowel space and vowel centralization. Another relevant aspect is the dynamic behavior of formant transitions in dyadochokinet exercises, to assess hypokinetic dysarthria in Parkinson’s Disease (PD). The objective of the study is to compare articulation in PD patients against a normative population from kinematic features estimated on formants using Information Theory to quantify their divergence with respect to normative subjects.

MATERIALS AND METHODS

Jaw-Tongue Biomechanical Model

Speech articulation depends on the activity of vocal tract structures, such as the jaw, tongue, lips and velo-pharynx, among others. These structures are moved by different muscles, which are activated by neuromotor pathways from cranial nerves [1]. The production of speech sounds depends on the positions of these structures and on their dynamic displacements.

Fig. 1: Jaw-Tongue Model. F: Fulcrum; T: Tongue; J: Jaw bone; H: Hyoid bone; f_sg: stylo-glossus force; f_m: masseter force; f_g: glosso-intrinsic forces; f_h: genio-hyoid force; f_w: gravity; X_a, Y_a: accelerometer normal and tangential; Δx, Δy: horizontal and vertical displacements of the reference point (P_{ref}) in the sagittal plane.

In the present paper the role of the jaw-tongue system, as depicted in Fig. 1 will be studied when affected by neuromotor degeneration induced by PD. The jaw-tongue biomechanical system is considered to be a third-order lever with lumped mass load concentrated in the reference point \{x_r, y_r\}. Harmonic oscillation \{Δx_r, Δy_r\} around the fulcrum (F: attachment to the skull) is assumed under forces acting on this system (see Fig. 1).

A kinematic correlate of articulation

The displacement of the reference point of the jaw-tongue system when observed over time may be described by an absolute kinematic velocity (AKV) defined as:

\[
|v_r| = B_1 \left( \frac{dx}{dt} \right)^2 + B_2 \left( \frac{dy}{dt} \right)^2 + B_{12} \frac{dx}{dt} \frac{dy}{dt}
\]

(1)

Where F_1 and F_2 are the first two formants, and B_1, B_2 and B_{12} are quadratic scaling factors relating movement and acoustics [2]. An important question on the use of kinematic features derived from acoustic correlates (F_1 and F_2) is to which extent formant dynamics can be associated to articulation kinematics (positions and velocities of the jaw-tongue center of masses).

The assessment of AKV as a reliable kinematic correlate of articulation is carried on the multiple signal recording framework described in Fig. 2.

Fig. 2: Speech, sEMG and Accelerometry recording.
A diadochokinetic exercise is carried on, consisting in
the fast and continuous repetition of the diphthong \([a:\text{i:}a]\), at
a rate of 2-3 repetitions per second. Inverse adaptive
filtering is used to estimate the vocal tract transfer function
from running speech in real time [3]. \(F_1\) and \(F_2\) are
evaluated from the transfer function. Surface electromyography on the masseter (sEMG) and three-
channel accelerometry (Acc) are recorded also
synchronously with speech. Sampling rates of sEMG and Acc are equalized to 500 Hz, as well as formant estimates,
which are produced each 2 ms. The validation of formant
dynamics to repesent kinematic variables is done by
regression of signals on the following relational chain:
sEMG > fm, yAcc > Δ y and Δ y > Δ F1, Δ F2. The results of
regression studies are given in Table 1.

Table 1: Regression results for the diadochokinetic
validation exercise. \(r\): correlation coefficient; \(p\): p-value; S:
Spearman; P: Pearson.

<table>
<thead>
<tr>
<th>Correlation</th>
<th>(r) (S)</th>
<th>(p) (S)</th>
<th>(r) (P)</th>
<th>(p) (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ y vs (f_m)</td>
<td>0.83</td>
<td>&lt;0.001</td>
<td>0.81</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(F_1) vs Δ y</td>
<td>-0.89</td>
<td>&lt;0.001</td>
<td>-0.89</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(F_2) vs Δ y</td>
<td>0.78</td>
<td>&lt;0.001</td>
<td>0.79</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

It may be seen that KLD presents a moderate but
statistically relevant correlation with respect to the time
interval since first diagnosis. Correlation is also relevant
with respect to freezing of gait, non-motor symptoms and
sleep disorders. No relevant correlation has been found to
UPDRS, mini-mental state or ACR and BDI scores.

Conclusions

Correlation studies between sEMG, Acc and speech
formant dynamics reveal important cause-effect relations
among these traits, which allow the definition of
articulation kinematic modelling. KLD from probability
densities of articulation kinematics (AKV) can be used to
grade the timely evolution of neurodegenerative processes,
after first diagnosis. No significant correlation has been found to
UPDRS, mini-mental state or ACR and BDI scores.

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