10th International Conference on Speech Prosody 2020
25-28 May 2020, Tokyo, Japan

Labialization and Prosodic Modulation in Italian Dysarthric Speech by Parkinsonian Speakers: A Preliminary Investigation

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Abstract

Movements by Parkinsonian speakers have often been reported as characterized by a reduction in amplitude and speed, due to the type of dysarthria that is usually associated to the disease, i.e. hypokinetic dysarthria. Such general features have an impact on both segmental and prosodic speech characteristics, inducing a reduction of both the oral phonetic space and the prosodic modulation realized by speakers. This paper aims at investigating both segmental and prosodic characteristics of Italian Parkinsonian speech, by devoting specific attention to 1) amplitude, duration and timing of labialization related to posterior vowels, as for the segmental level; 2) both duration of prosodic units (syllables, utterance) and amplitude, duration and timing of pitch events, as far as prosody is concerned. Acoustic and articulatory (AG501) data are reported on speech by four mild-to-severe Italian dysarthric Parkinson speakers and four peer healthy controls. The hypothesis is that, in line with the literature, measurements regarding Parkinson speech usually show reduced values in comparison to those regarding healthy speech. Besides the expected tendency to a reduction in speech gesture amplitude, pitch modulation and articulation rate, results suggest a complex picture that also involves increased values, possibly related to compensatory strategies.

Index Terms: Speech production, speech pathology, dysarthria, Parkinson's Desease, Italian, prosody, labialization, laryngeal and supralaryngeal gestures

1. Introduction

A reduction in the amplitude and speed of movements, that is hypokinesia and bradykinesia, are usually reported as characterizing hypokinetic dysarthria, which often afflicts subjects affected by Parkinson's Disease (PD) (e.g., [1], [2], [3]). As far as segmental features are concerned, a reduction of the vowel acoustic space and of the amplitude of speech gestures is usually found (e.g., [4], [5]), though duration of movements is expected not to change (or can decrease but the reduction of amplitude - and velocity – is not proportional [6]). However, some kinematic investigations also reported a greater amplitude in PD speech gestures ([7], [8]), even only on specific axes (such as for horizontal, antero-posterior, displacement [9]). Importantly, intra-speaker analyses showed that, despite reduction, segmental phonological distinctions are preserved as much as possible, thanks to compensation strategies [10].

Regarding prosodic characteristics, parkinsonian dysarthric speech has been described as monotonous and monoloudness. Specifically, it shows a small variation in pitch range and voice intensity, and it is characterized by a reduced implementation of stress, a strong variability of speech rate, with paroxysmal accelerations and the realization of inappropriate pauses ([11-14]). These prosodic characteristics are reported to be more marked in semispontaneous than in read speech [15] (where, for instance, an increased speed of reading may be observed, compromising articulation accuracy [16]), and changing depending on the disease severity [6].

In this paper, the attention is focused on both segmental and prosodic characteristics of Italian Parkinsonian speech, as investigations concerning the general reduction tendency at the segmental level gave heterogeneous results as far as Italian is concerned ([9],[10]), and prosody in Italian dysarthric speech has not been investigated yet, besides a very preliminary work [17]. Even though it reports preliminary data, the study also addresses issues regarding the prosody-phonetics interface.

2. Goals and hypotheses

The main goals are 1) to reach a better understanding of production strategies related to antero-posterior gestures, and 2) to offer a first description of prosodic parameters in (Lecce) Italian dysarthric speech. These goals are achieved by devoting specific attention to 1) amplitude, duration and timing of labialization related to posterior vowels as opposed to anterior vowels, as for the segmental level; 2) both duration of prosodic units (syllables, utterance, to also investigate articulation rate) and amplitude, duration and timing of pitch events, as for the prosodic level. The interaction between segmental and prosodic features is also considered.

The main hypothesis is that, in line with the literature, measurements regarding PD speech usually show reduced values in comparison to those regarding healthy speech. However, due to the interplay of linguistic factors, inducing speakers to maintain linguistic unit identity, and the impairment due to the disease, a) we expect to find also increased values concerning anterior-posterior gestures, in line with results observed in relation to tongue movements in (Lecce) Italian speech ([9], [10]). With regard to 2), we expect to find b) decreased pitch range values and changes in speech rate in PD speech, in line with the literature; we also expect to find changes in tonal target alignment [18], assuming that alignment can be regarded as a matter of intergestural coordination between laryngeal and supralaryngeal gestures [19].

3. Method

3.1. Corpus and recordings

The corpus is composed of three word nominal phrases, such as *Lu/i X blu* 'The blue X', where Xs are ˈCVCV disyllables, Vs are /i/-/u/ or /u/-/i/, and initial or intervocalic C may be voiced or unvoiced bilabial stops (/p/, /b/). Disyllables are [ˈpu.pi], [ˈpi.pu], [ˈbu.bi], [ˈbi.bu], preceded by the determiner Lu/Li (singular and plural masculine, respectively), as allowed by the local Italian variety. The target short sentences were presented as answers to questions eliciting broad focus interpretations.

 10.21437/SpeechProsody.2020-169

Four mild-to-severe dysarthric PD speakers from Lecce – Southern Italy (age 65-80) and four peer healthy controls (CTR) from the same geolinguistic area (matching age) participated in the study. The same severity level was reported for PD speakers according to clinical assessment; no relevant clinical issue was reported by CTR speakers. Each speaker read the corpus 7 times at a comfortable speech rate. Acoustic and articulatory data were collected synchronously by an EMA 3D AG501 (Carstens Med., GmbH) in a quiet room at CRIL (Lecce, Italy). The articulatory data were recorded by means of 7 sensors, glued on subjects: 2 on tongue mid-sagittal plane (dorsum and tip), 2 on lips vermillion border (upper and lower), 1 on the nose and 2 behind the ears for normalization.

3.2. Labelling and measurements

The acoustic signal was manually labelled in PRAAT as for both the segmental and the intonational level. As for the former, consonant (C) and vowel (V) boundaries were labelled. Regarding intonation, the initial (L1) and final fundamental frequency (F0) values of the initial rise (H), corresponding to the realization of the prenuclear (initial) pitch accent, as well as the final F0 fall (Ln), that is the nuclear (final) pitch accent, were identified and labelled (where H is also the max and Ln is the min F0 value). Duration of the consonant and vowel (C0,V0) composing the prenuclear syllable, carrying a pitch accent (that enhance segmental characteristics, e.g., the opposition between front/back Vs, and voiced/unvoiced Cs), as well as the duration of the other segments, were then automatically extracted. Other measures concerned F0 values at the abovementioned tonal landmarks, and first and second formant values (F1, F2, measured in the central 50 ms of the vowels). Segment durations were used to compute the duration of syllables (including that of the latter as an indication of final lengthening) and of the whole utterance. Utterance duration was exploited to calculate articulation rate, expressed by the average syllable duration, i.e., as the ratio between utterance duration and the actual number of syllables. F0 values were used to compute the global F0 range (H-Ln), the rise F0 range (H-L1), as well as the F0 peak alignment (specifically, its latency from the end of the syllable, i.e. the closest segmental landmark corresponding to a syllabic boundary), and the tonal target latency from each other (L1-H, H-Ln).

Articulatory data labeling was performed by means of MAYDAY [20]. For both tongue dorsum (TD) and lower lip (LL) track, and along both vertical and horizontal (anterior-posterior) axes, we labelled: gesture target, located at the zero velocity, and, for each tracked segment, the maximum velocity, labelled at the velocity peak of the relevant coil. Duration and amplitude of lower lip/tongue dorsum gestures were calculated. For instance, for each closing gesture, duration was calculated as the time interval between the maximum aperture and the maximum closure of articulators; the amplitude was calculated as the vertical/horizontal component of the displacement during gesture. Prosodic measures (such as articulatory syllable and articulatory utterance duration, latency between H tonal target and articulatory syllable boundary) were calculated with reference to gesture onset/offset (identifying the time point in which the articulator was leaving/reaching its stable position), automatically computed and labelled at 20% of the peak of the velocity module profile around the zero velocity. Articulatory final lengthening, was calculated as the interval between the final vowel peak velocity and the final vowel target [21].

As for statistical analysis, mixed models were implemented in R (lme4 [22], [23]). Fixed effects, with interaction terms, regarded linguistic factors such as *Voicing* (voiced vs. unvoiced) and *Vowel cycle* (Vcycle IU vs. UI, for, respectively, the /i-u-i/ and the /u-i-u/ cycle). *Population* (PD vs. CTR) and *Repetition* (7 levels) were rather introduced to take into account the impact of impairment. Intercepts for subjects, as well as by subjects random slopes were set in order to account for inter-subjects variability as for the realization of repetition. Visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality. In order to test the significance ($p<0.05$) of each fixed effect, a *Likelihood Ratio Test* was used.

4. Results

4.1. Acoustic results

Segmental measurements show that the Vcycle (IU: /i-u-i/ vs. UI: /u-i-u/ cycle) affects subjects' production, and pathological speakers seem to use a smaller vowel space than control ones at least in the horizontal dimension. The first formant value of the first accented vowel (V0) decreases by about 40 Hz ± 3.5 (S.E.) in the UI in comparison to the IU cyle ($\chi^2(1)=98.79$, $p<0.0001$); the second formant increases by about 1252 Hz ± 20.5 (S.E.) in the UI vs. IU cycle ($\chi^2(1)=611.37$, $p<0.0001$). However, in the case of F2, an interaction between Vcycle and Population is found ($\chi^2(1)=36.4$, $p<0.0001$), with F2 increasing less in PDs than in CTRs: it is higher for /u/ and lower for /i/, pointing to vowel space reduction on the anterior-posterior axis – Fig.1.

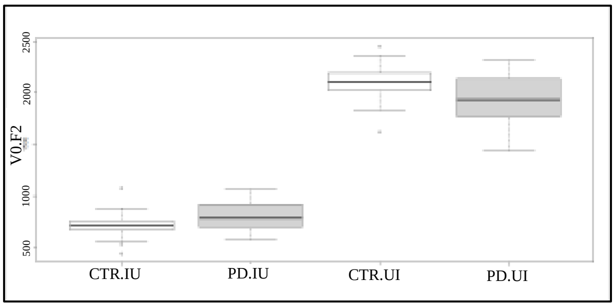

Figure 1: *Accented vowel F2 values (Hz) in /u/ (left) and /i/ vowels (right) by PD (grey) and CTR speakers (white)*

Syllable and utterance duration, as well as articulation rate, are affected by both the Vcycle and the Voicing factors, though the only difference between pathological and control subjects regards a slightly longer syllable duration in PD in the case of voiced consonants; no differences are detected in relation to final lengthening. The first accented syllable duration significantly decreases (by about 14 ms ± 3.8 S.E.) in the case /i/ (UI cycle), rather than /u/ is the nucleus ($\chi^2(1)=12.935$, $p=0.0003$). The syllable duration also decreases (by about 16 ms ± 3.8 S.E.) in the case unvoiced Cs are present ($\chi^2(1)=16.998$, $p<0.0001$). An interaction with Population is found ($\chi^2(1)=4.89$, $p=0.026$) as a longer duration is found in PD productions in the case of voiced consonants. Utterance duration, on the contrary, is longer (by about 37 ms Hz ± 10 S.E.) in the UI than in the IU cycle condition ($\chi^2(1)=13.08$, $p=0.0002$). As for the Voicing factor, the presence of unvoiced Cs lowers utterance duration (by about 53 ms ± 10 S.E.) ($\chi^2(1)=26.3$, $p<0.0001$). Along similar lines, the articulation rate is affected by Vcycle, with the UI condition causing a decrease of rate ($\chi^2(1)=13.08$, $p=0.0002$), i.e., an increase of syllable duration (about 9 ms ± 2.5 S.E.). The presence of voiced Cs rather than unvoiced ones, decreases the articulation rate ($\chi^2(1)=26.3$, $p<0.0001$), as increases syllable duration (by about 13 ms ± 2.5 S.E.). No significant effect regards the duration of the final syllable. Thus, no factor considered here, including the pathological vs. healthy condition, affects final lengthening.

On the other hand, PD speakers differ from CTR ones as for the pitch range exploited (H_Ln_F0), with PDs showing a reduced range (by about 16 Hz ± 7 S.E.) in comparison to CTRs ($\chi^2(1)=4.24$, $p=0.03$). No significant effect regards the F0 range of the initial rise (L1_H_F0).

The timing of prenuclear peaks with respect to segmental landmarks is not affected by the factors considered. On the contrary, the latency between tonal targets is affected by the Voicing factor, in that the latency between the low and high target in the initial rise (L1_H) and in the final fall (H_Ln) decreases because of the presence of unvoiced Cs (respectively ($\chi^2(1)=9.8$, $p=0.001$) and ($\chi^2(1)=9.29$, $p=0.002$)). Specifically, the L1_H latency decreases by about 13 ms (± 4 S.E.) and the H_Ln latency by about 20 ms ± 6 (S.E.). However, in the case of the H_Ln latency, a slight interaction with Population is found ($\chi^2(1)=3.48$, $p=0.06$), in that PD speakers show a longer latency in voiced Cs, while CTRs show a longer latency in the case of unvoiced Cs. Further, the H_Ln latency is affected by Vcycle ($\chi^2(1)=21.57$, $p<0.0001$), and is longer in the case of prenuclear /i/ (about 30 ms ± 6 S.E.).

4.2. Articulatory results

Vcycle affects the tongue vertical gesture, in both the gesture to the accented V (by about 15 mm ± 0.5 (S.E.); $\chi^2(1)=346.62$, $p<0.0001$), and that from it (by about 15.5 mm ± 0.53 (S.E.); $\chi^2(1)=334.33$, $p<0.0001$). Further, an interaction between Vcycle and the Population is found, in that the tongue vertical movement is wider in PDs than in CTRs, both in the cycle to the accented V ($\chi^2(1)=40.8$, $p=0.0001$) and in the tongue vertical gesture from it ($\chi^2(1)=65.7$, $p<0.0001$). These results are not consistent with those concerning the first formant, where Population does not seem to make a difference.

The tongue horizontal movement is also wider in PD than in CTR, both in the gesture to the accented V (by about 21 mm ± 0.43 (S.E.); ($\chi^2(1)=514.5$, $p<0.0001$), and in the gesture from it (by about 24 mm ± 0.52 (S.E.); ($\chi^2(1)=497.42$, $p<0.0001$). An interaction with Population is found, as the tongue movement is wider in PD than in CTR both in the cycle to the accented vowel ($\chi^2(1)=84{,}2$ $p=0.0001$) and in the tongue gesture from it ($\chi^2(1)=45.5$, $p=0.0001$) – Fig. 2. These results are not consistent with those concerning F2, which suggested a reduction of the vowel space in the anterior-posterior direction in PD speakers.

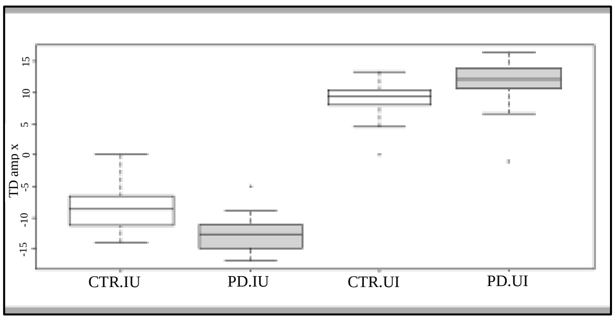

Figure 2: *Amplitude (mm) of the tongue horizontal gesture to the accented /u/ (left) and to the accented /i/ (right) in PD (grey) and CTR speakers (white)*

Interestingly, the lower lip horizontal gesture to the consonant, the onset of the accented syllable, is affected by Population ($\chi^2(1)=7.01$, $p=0.008$), as the gesture in PDs is significantly shorter (by about 1 mm ± 0.3 (S.E.). Vcycle also affects the gesture ($\chi^2(1)=116.23$, $p<0.0001$), decreasing its amplitude by about 2.7 mm ± 0.21 (S.E.)) – see Fig.3. As for the gesture from C to the postaccented vowel, Vcycle plays a significant role ($\chi^2(1)=69.17$, $p<0.0001$), increasing its amplitude by about 1.7 mm ± 0.18 (S.E.) in the UI vs. the IU condition. No effect of Population, nor an interaction with it, is found, though the gesture is slightly shorter in PD than in CTR speakers.

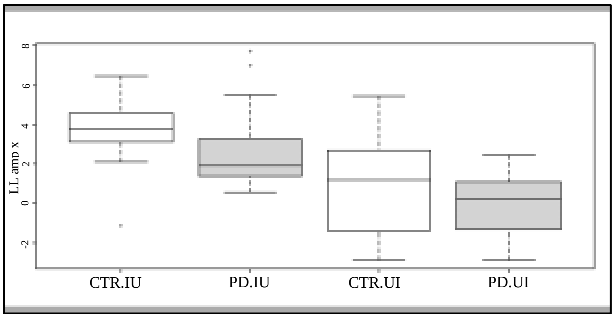

Figure 3: *Amplitude (mm) of the lower lip horizontal gesture to the accented /u/ (left) and to the accented /i/ (right) in PD (grey) and CTR speakers (white)*

As far as articulatory duration measurements are concerned, Voicing turns out to be less relevant factor than it was in acoustics, while, on the contrary, Population appears to be more relevant than in acoustics. Specifically, Voicing affects ($\chi^2(1)=7.93$, $p=0.004$) articulatory syllable duration, decreasing it by about 72 ms ± 26 (S.E.) in the case of unvoiced Cs (for CTR speakers and IU condition). However, no main effect is found for any factor on either articulatory utterance duration or articulation rate. Rather, for both, a alight crossover interaction is found between Population and Vcycle (utterance duration ($\chi^2(1)=3.52$, $p=0.06$); articulation rate ($\chi^2(1)=3.51$, $p=0.006$). In both cases, then, the effect of Cycle is opposite depending on the Population (longer values are found in relation to /i/ than to /u/ in PD subjects, and the other way around in CTR subjects). Finally, Population slightly affects articulatory final lengthening ($\chi^2(1)=3.18$, $p=0.07$), as PD speakers show increased values (by about 26 ms ± 13 S.E.) in comparison to CTRs (for IU cycle and voiced C).

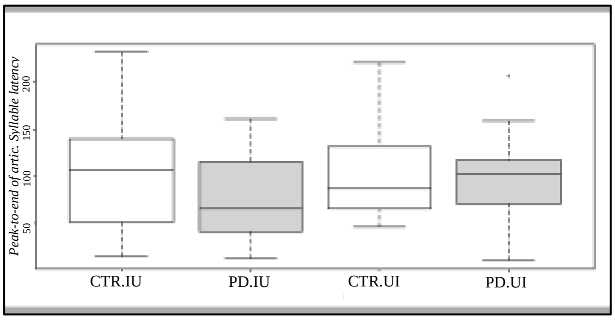

Figure 4: *Latency (ms) between peak and end of accented articulatory syllable including /u/ (left) and /i/ (right), in PD (grey) and CTR speakers (white)*

The prenuclear H timing with respect to the articulatory end of the accented syllable is affected by Voicing ($\chi^2(1)=14.68$, $p=0.0001$), which decreases it by about 14 ms ± 3 (S.E.) in the case of unvoiced Cs. Differently from what found in acoustics, the timing is also affected by Vcycle ($\chi^2(1)=8.66$, $p=0.0032$), which increases it by about 10 ms ± 3 (S.E.) in the case of accented /i/. An interaction with Population is found ($\chi^2(1)$=4.35, p=0.036), in that for PDs, differently from CTRs, the latency increases in syllables with accented /i/ vs. /u/ - Fig.4.

5. Discussion and conclusions

Regarding segmental measurements, acoustic results confirm expectations, showing that front /i/ and back /u/ vowels are significantly different, and, at least in the anterior-posterior dimension, PD speakers exploit a reduced vowel space. However, articulatory results put a different light on the abovementioned picture. As expected, the Vowel cycle (Vcycle /i-u-i/ vs. /u-i-u/) affects the tongue vertical gesture both to and from the accented syllable. However, the interaction between Vcycle and Population shows that the tongue vertical movement is wider in PD than in CTR speakers, as if the PD articulatory space in the vertical dimension was wider. These results are not consistent with acoustic ones (where Population did not seem to make a difference on F1), and show that an incresed amplitude may regard PD gestures on the vertical dimension. The analysis of tongue horizontal gestures gave results that also seem to contradict acoustic ones (which suggested a reduction of the vowel space on the antero-posterior dimension) - see also [9-10]. In fact, the tongue horizontal gestures (to and from the accented vowel) turn out to be wider in PD than in CTR subjects. Light in the matter is shed by the analysis of lower lip horizontal movement, due to protrusion. Besides an influence of Vcycle on gestures both to and from the consonant in the accented syllable, an interesting impact of Population is also found. Specifically, a slightly smaller lip horizontal gesture from the preaccented vowel to the accented consonant is found in PDs, in comparison to CTRs, pointing to the existence of a compensatory effect (which does not significant affect the gesture from the consonant to the accented vowel, though values are consistent with the compensatory strategy).

Acoustic measurements concerning duration investigated here do not seem to be majorly sensitive to PD dysarthria, as acoustic syllable and utterance duration, as well as articulation rate, are mainly affected by both the Vowel cycle and the Voicing factors. Specifically, the presence of voiced consonants and (a majority of) posterior/labialized vowels increase durations and decrease articulation rate. The only difference between PDs and CTRS regards the longer syllable duration in the case of voiced consonants in PDs' productions. Further, no differences across populations are detected in relation to final lengthening.

As far as duration measurements of articulatory events are concerned, Voicing turns out to be less relevant than it was in acoustics, while Population appears to be more relevant than in acoustics. Specifically, Voicing significantly affect only articulatory syllable duration (decreasing it in the case of unvoiced Cs). However, articulatory utterance duration and articulation rate are not affected by main effects, but rather by a cross over interaction between Population and Vcycle, showing that PDs behave somewhat differently from CTRs. This is only partially in line with the literature ([6], but see [16]), and again shows that different indications come from acoustic and articulatory data. As for articulatory final lengthening, PD speakers show slightly increased values in comparison to controls.

Concerning pitch characteristics, in line with the literature, acoustic results show that PD speech is characterized by a reduced pitch range. Importantly, this result was obtained here even though target utterances were very short and structurally simple. However, alignment measures concerning intonation, which are relevant for linguistic purposes [18], do not seem to be majorly affected by pathology. Only one tonal target-to-tonal target measure (H-Ln) seems to be sensitive to the interaction between Population and Voicing, as PD subjects increase the H-L tonal gesture duration if voiced Cs are realized (which is consistent with the abovementioned longer syllable duration in the same condition). The only articulatory measures considered was the prenuclear H tone timing with respect to the articulatory end of the accented syllable. Besides the influence of Voicing, such measure also turned out to be significantly affected by Vcycle and its interaction with Population (with an earlier peak articulatory alignment in PD accented /i/ than /u/ syllables). This seems to suggest that for intonation may hold true what was previously found for segmental aspects, i.e., compensation strategies allow speakers to maintain contrasts and acoustic information which is relevant from the phonological point of view [10]. However, articulatory data seem to offer insight on such compensation strategies, offering additional information.

To sum up, besides the expected general tendency to a reduction, e.g., in speech gesture amplitude and pitch modulation, the analysis showed a more complex picture, involving also increased values, possibly related to compensatory strategies. A deep understanding of such compensatory strategies is needed, and articulatory data appear to be crucial in this direction. In relation to the first goal of the paper, articulatory information showed that the wide tongue movement observed despite a reduction of the acoustic space in PD speakers, could be due to a less wide lip protrusion gesture. As for the second goal, the paper offered a first description of prosodic characteristics in (Lecce) Italian dysarthric speech. Concerning duration, results show that articulatory characteristics seem to be affected by dysasrthria more than acoustic ones. This is only partially in line with the literature ([6], but see [16]), but it may show that articulatory data offer insights on speakers production strategies.

Further work is needed to deepen the issue, more deeply investigating the impact of lip gesture on the characteristics of segmental information, but also the impact on prosody modulation of articulatory information that do not relate only on lips (e.g., face and head movements)

Last but not least, the influence of linguistic factors, such as different voicing consonantal features and vowel sequences, proved to be significant in affecting the measures performed on the segmental and, to a certain extent, the prosodic level. On the other hand, among the factors included to account for pathology, only the opposition between pathological and control speech turned out to have an impact on the selected measures. Importantly, the repetition factor, considered as a measure of tiring due to the length of the task, never affected results. This suggests that either tiring does not affect PD speaker performances or, more probably, the way the effect was investigated here is not ideal. Further work may check the influence of utterance length and/or sentence complexity, rather than the length of the task.

6. Acknowledgements

This work was partially funded by the PRIN 2017 project 2017JNKCYZ. We thank all the pathological and control subjects who participated in the experiment, dott. M. Iraci who helped in speech recordings, and dott. F. Sigona who offered technological support for data extraction.

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