ACOUSTIC CHANGE OVER TIME IN SPEECH OF ONE BILINGUAL INDIVIDUAL WITH PARKINSON'S DISEASE

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ABSTRACT

Speech changes appear in most speakers with Parkinson's disease (PD), but very little is known about longitudinal speech changes in bilingual people with PD. The aim of this exploratory single case study is to explore such changes in two working languages of one individual with PD. For this purpose, we collected the time series of 36 recordings done over 3.6 years, with recording timeline including the pre-, concurrent, and post-speech therapy periods. We analysed recordings of different tasks performed in Dutch and English, examining a set of conventional speech features related to phonation, prosody and articulation. The results of the linear trend estimation demonstrate similar trends irrespective of the spoken language, while some of the measurements, e.g. speech rate, demonstrate more pronounced and significant trends in English only. Exploratory acoustic analysis also provided evidence of a speech therapy effect in both languages, though the therapy was administered only in Dutch.

Keywords: Parkinson's disease, acoustics, dysarthria, prosody, bilingualism

1. INTRODUCTION

Speech and communication changes are almost certain to happen for people with Parkinson's disease (hereafter, PwPD). It was reported that 80-90% of PwPD experience voice changes and 45-50% show articulation change due to hypokinetic dysarthria (HD) [1]. Studies on speech production in PwPD often focus on the conventional features that are clinically interpretable and can be correlated with HD auditory-perceptual assessments (for details on conventional and non-conventional speech features see [2]). Among the most described conventional speech features in HD are fundamental frequency (f_0) deviations associated with monopitch [3], distorted rhythm [4], and reduced intensity variability associated with monoloudness [3].

There are only a few studies that explore longitudinal speech changes in PwPD, most of which analysed recordings collected at two time points with intervals between them ranging from seven months [4] to 3.7 years [5]. The findings demonstrate reduction in f_0 variability [6], instability of steady syllable repetition [7], increased speech rate [5], deteriorations of voice quality and of articulatory velocity and precision [7]. In one case study describing a longitudinal speech analysis based on television archives over an 11-year period authors found that changes in f_0 variability can be detected as early as five years prior to diagnosis [8].

However, there is hardly any research done on bilingual PwPD not to mention longitudinal effects of PD on bilingual speech. This constitutes a big gap in existing literature, given that most people in the world are not monolingual and the increasing global mobility actively reinforces multilingualism. To our knowledge, only two studies focused on speech and language in bilingual PwPD [9, 10] and no publications reported the effects of speech therapy in bilingual PwPD. The authors of [9, 10] demonstrated that their group of PwPD had more phonological, morphological, and syntactic errors in their first language, Friulian, rather than in their second language, Italian.

This study addresses the literature gap by focusing on longitudinal acoustic changes in speech of a bilingual person with PD. The first goal is to explore if the acoustic changes are similar in two working languages of the bilingual participant with PD, Dutch and English. In the light of previous studies and despite the differences in phonological systems, we expected to see the typically occurring PD effects in speech acoustics (e.g., the decrease in f_0 variability, the rise in mean f_0) to become more prominent with time in both languages [11, 2]. The second goal is to explore if the general speech therapy effect is present in the measurements of acoustic features in either language, given that the speech therapy was administered in Dutch. Based on the therapy goals (see 2.1), we hypothesized that effect would be present for the voice quality and f_0 measurements in both languages. Considering speaker's bilingualism and the complex character of linguistic transfer and feature interference [12], we did not expect to see speech therapy effects on any particular speech characteristic just in one language.

2. METHODS

The present study uses a time series design following one individual's speech over 3.6 years. The collection and analysis of the material was approved by the Ethical Committee of of University Groningen, Campus Fryslân.

2.1. Participant

One speaker with PD, a sequential bilingual, participated in the longitudinal data collection during 185 weeks. He reported to consistently use two languages on a daily basis: Dutch and English. He was diagnosed with idiopathic PD six years prior to the beginning of the data collection, at the age of 60. He has not been diagnosed with hypokinetic dysarthria, but has a history of developmental stuttering. During week 46 the participant reported having a cold. After the first 12 recording sessions, he began with speech therapy in Dutch that according to his speech therapist was largely based on the Lee Silverman Voice Treatment [11] with the main focus being on increasing vocal intensity, lowering pitch and increasing intelligibility of phonemic groups. During the next eight sessions the participant had ongoing speech therapy until he stopped by session 22. Throughout the whole period of recordings, the participant was on stable dopamine-replacement medication (Sinemet).

2.2. Recording procedure

Speech tasks in each session included sustained phonation of the vowel /a:/, interview with an open question, description of one of the Heaton pictures [13] and of a short video clip taken from the freely available works of Charlie Chaplin, and reading of the 'North Wind and the Sun' passage. All tasks were performed first in English and subsequently in Dutch, with instructions provided both orally and with the slide show. The first two sessions lacked video description, and session 31 lacked picture description due to technical reasons. The sessions happened roughly every month (mean interval is 5.3 weeks, SD = 2.6 weeks) from one to three hours after medication intake. Based on the previous research [14], we did not expect time of the day or moment of medication to influence our participant's speech. The first 28 recording sessions took place in quiet rooms with the Zoom H2 recorder placed at around a 40 cm distance. Starting with session 29 the sessions took place mostly via Zoom calls due to COVID-19 restrictions and the participant recorded himseld with the Dictaphone app on his iPhone 10 placed at around a 40 cm distance. The reliability of the data collected during online sessions was ensured by comparison of the quality and acoustic measurements of two sets of recordings collected simultaneously with iPhone 10 and Zoom H2 during two offline sessions.

2.3. Acoustic measurements

We focused on conventional features characteristic of phonation, prosody, and articulation aspects of speech affected by PD as captured by prolonged phonation, monologue and reading tasks [2]. All measurements and subsequent analyses were performed separately for the different tasks to avoid losing task-related information [15].

We included five features from the domain of prosody. For the fundamental frequency (f_0), f_0 means and f_0 variability (f_0 coefficients of variation) calculation we used a Python f_0 tracking script based on the robust algorithm for pitch tracking (RAPT) [16] implemented in the Speech Signal Toolkit [17]. Speech rate and articulation rate were calculated with a Praat script [18]. Speech rate was measured as the number of syllables divided by the total time of the recording, articulation rate – as the number of syllables divided by phonation time. Feature of inappropriate silences was calculated from the results of the same Praat script [18] as the number of pauses relative to total speech time after removing periods of silence lasting less than 60 ms [2]. For phonation and voice quality, we included three features: maximum phonation time (MPT), jitter and harmonics-to-noise ratio (HNR) measured from the prolonged phonation (/a:/) recordings. We also included two features related to articulation: the means of first two formants (F1 and F2) calculated from the prolonged phonation recordings. Because the recordings in the current study were done without strict supervision over the distance between speaker and the microphone, the intensity measurements had to be excluded from the analysis.

2.4. Statistical analyses

Given the study's exploratory focus and the time series nature of the data, we estimated linear trends for the selected speech features using simple linear regression on the dataset after excluding one session where the participant had residual effects of a cold (week 46). To determine whether the results of the linear regression analyses were not random we applied the Monte Carlo simulation by randomizing the measurements 1000 times and calculating the slope for every randomized set of measurements. We evaluated each resulted distribution of slopes by calculating its mean, SD and standard error.

To explore the general absence or presence of the therapy effect on each feature we analysed the dataset after deducting general linear trends from each data point, as such trends could reflect both the progression of PD and/or the general effect of ageing [19]. After the trend deduction, based on Levene's test results we conducted either non-parametric Welch's F tests or one-way ANOVAs followed up with Tukey post-hoc tests to compare measurements 'before' and 'during' as well as 'during' and 'after' therapy. Additionally, with Kolmogorov-Smirnov two-sample test we compared therapy measurements for the absolute values of f_0 to avoid any information loss by aggregating features per session.

3. RESULTS

3.1. Prolonged phonation

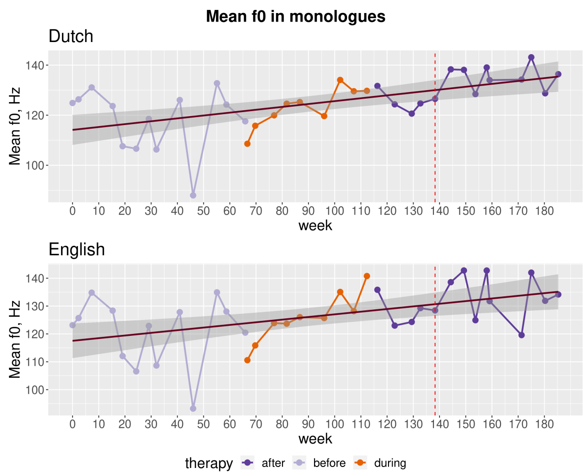
Analyses of HNR and Jitter showed no significant decline or rise. However, MPT demonstrated a significant decline: $R^2 = 0.15, F(1,33) = 5.91, p = 0.02$. The Monte Carlo analysis confirmed that it was not random. Changes of mean f_0 and F1 showed no trend, while the significant rises were present in f_0 ($R^2 = 0.5, F(1,33) = 32.76, p < .001$) and for F2 ($R^2 = 0.2, F(1,33) = 8.42, p = 0.007$). Monte Carlo analysis showed that these were also not random. After correcting for multiple comparisons with the Bonferroni method, the only significant results were present in f_0 ($p < .001$) and F2 ($p = 0.039$) trends.

Analysis of therapy effect yielded no significant results for any of the above features. For the absolute f_0 values, the result of the Kolmogorov-Smirnov test indicated that both pairs of the distributions were significantly different ('before'-'during': $D = 0.38$, $p < .001$,'during'-'after': $D = 0.16$, $p < .001$).

3.2. Spontaneous speech

Linear regression analysis resulted in significant trends for f_0 means over time in both languages (Dutch: $R^2 = 0.34, F(1,34) = 17.52, p < .001$; English: $R^2 = 0.25, F(1,34) = 11.15, p = 0.002$). Monte Carlo analysis confirmed that the results were not random. Bonferroni adjustment for f_0 measurements showed the preserved significance for mean f_0 both in Dutch ($p = 0.002$) and in English ($p = 0.008$).

Figure 1: f_0 means over time in two languages.



In the comparison of the therapy stages we tested the absolute values of f_0 and found no significant differences in f_0 variability or f_0 means. The results of Kolmogorov-Smirnov test for f_0 values at different stages of the therapy in Dutch and in English were found to be significant for comparisons of 'before'-'during' (for both languages, $D = 0.1$, $p < .001$) and 'during'-'after' (for both languages, $D = 0.1$, $p < .001$). Analysis of number of inappropriate pauses yilded no significant resluts.

3.3. Reading

Speech and articulation rates showed no significant trend over time. The analysis of the therapy effect on the rate measurements demonstrated one significant difference – for speech rate in English reading. An ANOVA test showed the differences between stages were significant, $F(2,32) = 4.37, p = 0.021$. A post hoc Tukey test showed the significant difference between 'before' and 'during' therapy stages ($p = 0.024$) and 'during' and 'after' therapy stages ($p = 0.04$). The differences in means in post hoc analysis demonstrated that mean value of speech rate was lowest during therapy. Linear regression analysis showed significant trends in f_0 variability over time for English reading ($R^2 = 0.17, F(1,34) = 7.07, p = 0.012$) and in mean f_0 in both Dutch and English reading (Dutch: $R^2 = 0.26, F(1,33) = 11.53, p = 0.002$; English: $R^2 = 0.22, F(1,33) = 9.51, p = 0.004$). Monte Carlo analysis confirmed that the results were not random. The Bonferroni adjustment for f_0 measurements showed the preserved significance for mean f_0 both in Dutch ($p = 0.002$) and in English ($p = 0.008$), and for f_0 variability in English ($p = 0.004$).

Analysis of therapy effect showed no significant differences in mean values of f_0 while there were significant differences in f_0 variability in English reading. One-way ANOVA yielded $F(2,32) = 6.18, p = 0.005$. The post hoc Tukey test showed the significant difference between 'before' and 'after' therapy stages ($p = 0.004$) with f_0 variability in English reading being lower after therapy. Once again, we tested the absolute values of f_0, the results of Kolmogorov-Smirnov test were found to be significant for comarisons of 'before'-'during' (for both languages, $D = 0.11$, $p < .001$) and 'during'-'after' (for both languages, $D = 0.13$, $p < .001$). Analysis of number of inappropriate pauses yilded no significant resluts.

4. DISCUSSION

The principal goal of this single case study was to explore changes in two languages, Dutch and English, in the time series of 36 recordings done over 3.6-years in a bilingual speaker with PD. We explored 10 conventional speech features measured from prolonged phonation, monologue and reading tasks. Among features related to articulation and phonation, we found significant changes in MPT and F2 with only F2 changes remaining significant after the Bonferroni adjustment. Nevertheless, the observed changes in MPT measure, characterizing the aerodynamic efficiency of the vocal tract, are in line with the descriptions of the clinical picture of HD related to reduction in the total amount of air expended during maximum phonation in PwPD [11]. The significant falling trend in F2 suggests presence of the centralization effects progression in vowels, which might be more apparent with respect to the reduced tongue movements as there were no significant changes in F1 values. The significance of a raising trend in mean f_0 with time is also in line with the changes caused by PD [11] and has also been noted by [19] in their elderly male group.

In the recordings of two other tasks, monologues and reading, we found significant trends in f_0 means for both languages, which is consistent with our findings for prolonged phonation. There were no significant trends in speech or articulation rates or in inappropriate silences contradicting the findings of [6] who found speech rate decline in male group with PD. A significant trend in f_0 variability was present in English reading, while no significant changes were found in Dutch reading and monologues. This larger range in variability values in Dutch reading throughout the sessions can possibly be explained by more comfortable intoning of read text in the speaker's first language. These findings are partially in line with the previous study by [6], who found no significant change in f_0 variability in PwPD with time. Yet, the presence of a significant trend in English reading requires further investigation. The lack of significant trends for speech and articulation rates, or for the number of inappropriate silences in both languages appears to be a positive sign of their stability in the disease progression. This, however, is indirectly against the findings of [9, 10], who demonstrated higher mistake rates in phonology, morphology and syntax in the speakers' first language. The presence of mistakes on higher levels, such as syntax and morphology, potentially could have correlated with the amount of pauses or rate changes over time. Regarding the effect of speech therapy, with the removal of the general trend we found significant differences for f_0 in periods with and without therapy for all tasks in both languages of the participant. Interestingly, we also found significant differences between therapy stages for speech rate and for f_0 variability in reading, but only for English. These findings suggest the therapy effect transfer. Literature does not provide any information into speech therapy effects in bilingual PwPD, and our results are exploratory.

Our study has several limitations. First, being a single case study it prevents us from making any generalizations. Second, it has an exploratory nature: we analysed the presence of linear trends and compared distribution shapes of our data. Thus, while no significant linear trends were found for some features, we cannot be sure there is no change present. In the future research, exploring non-linearity of the time-series data and expanding the list of features may provide additional insights into the nature of acoustic change and therapy effects in both languages. Contrary to the common pretest-posttest designs, the results of studies with frequent measurements could paint a more detailed picture of the speech disorder progression providing speech therapists with important information about the 'process' rather than the 'product' of speech change or therapy effects.

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