



Float Like a Butterfly Sting Like a Bee: Changes in Speech Preceded Parkinsonism Diagnosis for Muhammad Ali

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Abstract

Early identification of the onset of neurological disease is critical for testing drugs or interventions to halt or slow progression. Speech production has been proposed as an early indicator of neurological impairment. However, for speech to be useful for early detection, speech changes should be measurable from uncontrolled conversational speech collected passively in natural recording environments over extended periods of time. Such longitudinal speech data sets for testing the robustness of algorithms are difficult to acquire. In this paper, we exploit YouTube interviews from Muhammad Ali from 1968 to 1981, before his 1984 diagnosis of parkinsonism¹. The interviews are unscripted, conversational in nature, and of varying fidelity. We measured changes in speech production from the Ali interviews and analyzed these changes relative to a coded registry of blows Mr. Ali received in each of his boxing matches over time. This provided a rich and unique opportunity to evaluate speech change as both a function of disease progression and as a function of fight history. Multivariate analyses revealed changes in prosody and articulation consistent with hypokinetic dysarthria over time, and a relationship between reduced speech intonation and the amount of time elapsed since the most recent fight preceding the interview.

Index Terms: Parkinson’s disease, parkinsonism speech production, prosody, articulation, Muhammad Ali

1. Introduction

Early identification of the onset of neurological disease is critical for testing drugs or interventions to halt or slow progression. Changes in speech are often early harbingers of degenerative disease and have been shown to be among the first symptoms for many individuals developing parkinsonism or Parkinson’s disease [2, 3, 4, 5]. However, because it’s hard to predict who will eventually develop the disease, the vast majority of these biomarker development studies have not followed patients pre-diagnosis. Instead, most have used cross-sectional data from many participants at snapshot points in the progression of their illness to test the sensitivity of their methods [6, 7]. Typical methods for documenting these changes involve experimental protocols to ensure high fidelity recordings or carefully constructed speech material from patients at-risk or post-diagnosis. This approach is prohibitive for pre-clinical detection when neuroprotective therapies hold the most promise. For speech to be useful for early detection, speech changes should be mea-

surable from uncontrolled conversational speech collected passively in natural recording environments over extended periods of time. However, such longitudinal speech sets for testing the robustness of algorithms are difficult to come by. In the present report, we exploit retrospective speech samples from a public figure diagnosed with parkinsonism and track his changes in speech production over time.

Heavyweight boxing legend Muhammad Ali was diagnosed with parkinsonism in 1984, but a great deal of anecdotal evidence suggested neurological damage long before that diagnosis and long before his retirement from boxing. Dr. Ferdie Pacheco, a physician who worked in Ali’s corner during many fights, said in an interview from 1978, “Cosmetically he looks the same, but his reflexes are not there. Now everybody can hit him. And now he’s slurring his words. Which is the sine qua non of brain damage” [8]. Two years later, Ali’s father told the New York Times he had noticed the same thing as Pacheco. “The way he talks, I noticed that at times, it’s not too clear” [9]. At approximately the same time, in 1980, boxing promoter Bob Arum said: “Just about everyone who is close to Ali has remarked on the way he has been slurring his words and talking slower” [10]. Ali himself became aware of the concerns. Prior to his final fight in 1981 he told one newspaper columnist: “They say I have brain damage, can’t talk no more. How do I sound now?” [11].

The changes in speech noted in the anecdotes are consistent with parkinsonism affecting the basal ganglia circuitry, which regulates spatio-temporal aspects of motor planning and control. Degeneration of these neural circuits manifest in speech as hypokinetic dysarthria, characterized by imprecise articulation (slurring); overall slowed speech but with rushes of rapid mumbled speech (mumbling, stuttering), reduced intonation (monotone, or lacking melody), and a weak, breathy voice [12, 13]. However, the acute and/or cumulative effects of boxing on his brain may have contributed to the degradation of speech over time. In the present report, we exploit retrospective speech samples from Ali and track his speech prior to diagnosis to determine whether we can identify early early signs of the disorder.

Many existing studies have revealed that atypical speech production, including imprecise articulation, variability in speaking rate, monoloudness, and reduced intonation, are apparent during the very early stages of the disease [4, 14, 15, 16]. This has led to a number of methods for automated diagnosis of Parkinson’s disease (PD) based on speech production [17, 18, 19]. The vast majority of these methods and algorithms are evaluated on cross-sectional databases with controlled stimuli recorded in controlled environments to detect PD or evaluate

¹Mr. Ali’s original diagnosis was Parkinson’s syndrome (parkinsonism) rather than idiopathic Parkinson’s disease [1].

its severity [18, 20, 21]. Very few studies have analyzed longitudinal changes in conversational speech preceding diagnosis [22, 23].

The purpose of our study is to explore whether automated measures of speech production can be used to analyze conversational speech samples in uncontrolled environments in order to detect early symptoms of parkinsonism and PD. We use publicly available interviews from Muhammad Ali from 1968 to 1981, and measure perceptual dimensions of his speech expected to change with hypokinetic dysarthria, including speaking rate, vowel production precision, and intonation. The speech samples from these interviews are conversational and of varying quality due to background noise and changing recording conditions. As a result, we first use Amazon Mechanical Turk to identify all intervals of speech (3-sec or longer) where only Ali was speaking; then we automatically estimate the speaking rate, pitch variability, loudness variability, and vowel space area from the data. Results reveal that Ali’s speaking rate sharply declined over the years, as did his ability to precisely articulate distinctive vowels. In addition, the data shows that the number of days elapsed since the last fight was related to intonational variability.

2. Methods

The objectives of this study were to: (1) track longitudinal changes in speech production for Muhammad Ali prior to his diagnosis in 1984 and (2) to explore the relationship between changes in speech production and the frequency/severity of hits he experienced in boxing matches. Below we describe the speech data used in the study, the boxing match analytics, the measures of speech production extracted from the speech data, and the statistical methodology.

2.1. Speech data collection and annotation

We used interviews with Muhammad Ali available on YouTube as our data source. In Table 1, we provide a list of the interviews used in the study, their date, and a brief description. The interviews with Ali contained speech from other individuals as well. We used Amazon Mechanical Turk to identify all segments (3 sec or longer) where only Ali was speaking. We set up an Amazon Mechanical Turk experiment where we asked raters to carefully listen to each interview and mark the start-time and end-time of a segment where only Ali was speaking. To ensure that listeners were carefully performing the task, we used two raters for each interview and calculated a reliability rating by comparing the agreement between the two raters. The agreement was calculated by converting the ratings from a single rater to a binary vector that spanned the duration of the interview with 0.5 sec resolution. In other words, for each 0.5 sec interval, the binary vector is labeled as either 1 (only Ali speaking) or 0 (other people speaking). This vector was calculated for both raters and we only used segments for which there was an agreement exceeding 90% between the two raters. Finally, we manually listened to a random subset of the selected clips to ensure that they only contained speech from Ali². To challenge the algorithms, no attempt was made to control for content or recording conditions in this data set.

²The speech samples from each interview can be downloaded at <http://www.public.asu.edu/~7Evisar/software/AliSpeechData.zip>

Table 1: *Date and description of the Muhammad Ali interviews analyzed for changes in speech production*

Date	Description
6/68	Bud Collins interview with Muhammad Ali discussing boxing, religion and race.
12/68	Interview about Ali’s refusal to accept military induction.
8/69	David Frost interview with Muhammad Ali discussing religion and race.
10/69	Ali talks to Joe Namath and Dick Schaap on The Joe Namath Show.
10/69	Ali interviewed about modern boxers versus earlier boxers.
9/70	Cus D’Amato interviews Ali about boxing.
10/71	Michael Parkinson interviews Ali about race on BBC.
1/72	Nikki Giovanni interviews Ali about race and culture.
7/72	Irish journalist interviews Ali on race and boxing.
5/75	Harold Bell interviews Ali about boxing and religion.
9/74	David Frost interviews Ali about upcoming George Foreman fight.
12/4	Ali on British program called “An Audience With Muhammad Ali”.
2/75	Mike Douglas interviews Ali about upcoming Wepner fight.
12/75	Dinah Shore interviews Ali on boxing and life.
2/76	Howard Cosell interviews Ali about Rocky Marciano.
3/76	Merv Griffin interviews Ali before Larry Holmes fight.
3/76	Muhammad Ali Interview on Face the Nation.
7/77	Ali interviewed about boxing and religion in Newcastle, England.
3/78	Dick Cavett interviews Ali after loss to Leon Spinks.
5/78	Barbara Walters interviews Ali on boxing and life.
12/78	Ali on British program called “This Is Your Life.”
8/80	Merv Griffin interviews Ali before Larry Holmes fight.
1/81	Michael Parkinson interviews Ali about boxing and more on BBC.

2.2. Boxing match analytics

In addition to the interviews, we also obtained fight-by-fight punch statistics for each of Ali’s fights. The analytics were obtained from a company that manually analyzes boxing match data, CompuBox³. The data they provided included, for each of Ali’s fights, the date of the fight, the number of jabs attempted by the opponent, the number of jabs landed by the opponent, the number of power punches attempted by the opponent, and the number of power punches landed.

2.3. Speech measures

Using the data from the speech clips of only Ali speaking, we calculate the following three measures:

Speaking rate: An estimate of the speaking rate (SR), in syllables/sec, for each clip in each interview was calculated using the speaking rate estimation algorithm described in [24]. This SR estimation algorithm has already been validated on this data [25]. For a subset of 10 interviews, we manually measured the

³<http://compuboxonline.com>

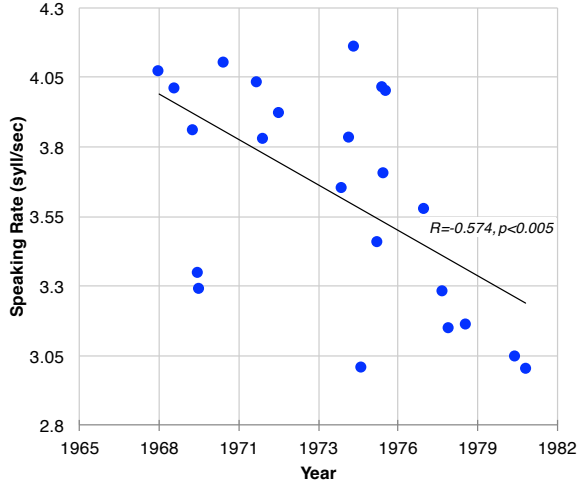


Figure 1: Muhammad Ali’s declining speaking rate estimated between for the period between 1968 - 1981. The analysis reveals a statistically significant decline in speaking rate over the years [$r = -0.574, p < 0.005$].

SR by transcribing the data and counting the syllables. The correlation coefficient between the algorithm-estimated rate and the manually-estimated rate is 0.88. The SRs for all clips in an interview were averaged to obtain an estimate of the average rate for that interview.

Intonational variability: For each interview, we estimate the F_0 contour of Ali’s speech using three state-of-the-art methods and only use samples for which there is agreement among the three methods (within 10 Hz of each other) [26, 27, 28]. The algorithms estimate F_0 using a 10 ms frame with 50% overlap. We also estimate the long-term energy contour (as a proxy for loudness) for each interview at the same frame rate. For each interview, we estimate the pitch and loudness range by estimating the difference between pitch/energy values at the 90th percentile and the 10th percentile. It is these ranges that we track across the interviews as measures of intonational variability.

Vowel space area: We measure vowel precision using the vowel space area (VSA), a measure of vowel dispersion in the space spanned by formants F_1 and F_2 [29, 30]. This metric has been previously identified as a correlate of intelligibility in dysarthric speech [31, 32]. We quantify the drop in precision by measuring the vowel space area using the speech clips from interviews given between 1968-1977 and compare it against the VSA from interviews between 1977-1981. We use the automated algorithm in [29] for estimating the VSA.

Unlike speaking rate, much more data are needed to estimate the VSA since it requires multiple samples of each produced vowel. As a result, we cannot generate a reliable estimate of the VSA for individual clips or even individual interviews. As an alternative, we estimate the VSA from combined clips prior to a cutoff year (1977) and compare against the VSA from combined clips following the cutoff year. We selected the cutoff year based on careful perceptual evaluation of the data by a speech-language pathologist (SLP). The SLP identified a noticeable change in the speech production following the 1977 interviews. Our aim was to see whether this perceptual change could be detected algorithmically using the VSA.

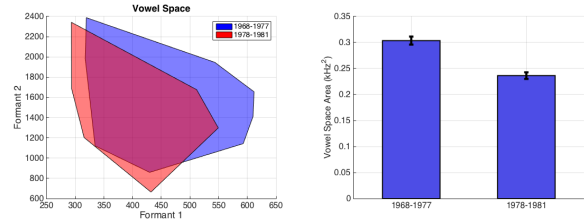


Figure 2: Muhammad Ali’s vowel space area estimated for two periods: 1968 - 1977 and 1978 - 1981.

2.4. Statistical Analysis

Longitudinal Analysis: We use Pearson correlation analysis to study the relationship between Ali’s age and three characteristics of speech: speaking rate, pitch range, and loudness range. For the vowel space area, we use an unpaired t -test to determine whether there is a statistically significant difference between the VSA from 1968-1977 and 1978-1981.

Multivariate Analysis: To better understand the other variables impacting Ali’s speech, we use multivariate regression to evaluate the relationship between boxing statistics and the three speech characteristics (speaking rate, pitch range, loudness range). The independent variables used in the analysis include age, the number of rounds his last fight lasted, the number of jabs his opponent landed in his last fight, the number of power punches his opponent landed in his last fight, and the number of days since his last fight. For all analysis, statistical significance was defined as $\alpha = 0.05$.

3. Results and Discussion

3.1. Longitudinal Analysis

In this section we analyze changes in speaking rate, pitch range, vowel space area, and loudness range over Ali’s career. The results show that there is a strong negative correlation between speaking rate and age [$r = -0.574; p < 0.001$]; however no significant correlation was found for either pitch or loudness range. In Fig. 1, we show the average speaking rate (SR), as measured by the number of syllables/sec. From the figure it is clear that SR was reduced by $\sim 26\%$ over the years, starting at 4.07 syll/sec and ending at 3.00 syl/sec. This is also clear from listening to the interviews.

In addition to the speaking rate, we also analyze Ali’s articulatory precision using the vowel space area. In the left panel of Fig. 2, we show the VSA prior to 1977 and after 1977 on the same plot. The VSA prior to 1977 is 0.305kHz^2 and after 1977 is 0.234kHz^2 . For both periods, we use bootstrap sampling to estimate the variance of the sample VSA and plot the VSA mean and standard deviation for the two intervals in the right panel of Fig. 2. An unpaired t -test reveals a statistically significant difference in the VSA between these two periods with $p < 0.0001$.

The changes in speaking rate over time are largely consistent with other studies. The disturbances in rhythm are likely due to parkinsonism affecting the circuitry in the basal ganglia [33, 34]. A number of studies have shown that changes in speaking rate often accompany Parkinson’s disease [35], and can serve as a leading indicator [5]. Vowel articulation is also

known to be impacted by PD. For example, in [31], Skodda et al. show that the VSA was reduced in 34 male speakers with mild PD compared to a group of age-matched healthy controls. They studied the use of the VSA and a related metric, the vowel articulation index, as possible markers of PD progression in a subsequent study [32]. Studies have interpreted the first formant as relating to the jaw opening and the second formant as relating to tongue position during speech production [36]. With this interpretation, the reduced VSA in Fig. 2 implies that there was reduced displacement of the articulators when Ali spoke after 1977.

It is surprising that the features aiming to measure intonational variation (pitch range and loudness range) did not exhibit a significant longitudinal decline. A number of existing studies show that one of the defining perceptual features of hypokinetic dysarthria is reduced variation in loudness and in pitch [3, 37]. We posit that this could be due to the effects of the repeated head trauma experienced in the boxing matches. We control for these factors in the ensuing section using a multivariate statistical model.

3.2. Multivariate Analysis

Next we consider multivariate regression models between the independent variables (IV): age, number of punches (jabs), number of punches (power) and days since last fight, and the three dependent variables (DV): pitch range, loudness range, and speaking rate. The results of the multivariate regression are shown in Table 2. In an attempt to study the effects of boxing matches on speech production, we restrict our analysis to only interviews that occurred within 1 year of the last boxing match. This reduces the number of interviews from the 23 interviews in Table 1 to a subset of 16 interviews. For pitch range, a significant regression equation was found $F(5, 10) = 3.530, p = 0.042$ with an R^2 of 0.638. For loudness range, a significant regression equation was found $F(5, 10) = 2.657, p = 0.088$ with an R^2 of 0.571. For rate, a significant regression equation was found $F(5, 10) = 3.826, p = 0.034$ with an R^2 of 0.657.

It is clear from Table 2 that there is a statistically significant relationship between both pitch range and loudness range and the number of days elapsed since the last fight. Immediately following a fight, Ali seems to exhibit monoloudness and monopitch; however as time after a fight elapses, Ali becomes more animated in his speech. Both monoloudness and monopitch are associated with hypokinetic dysarthria and we would expect to see a longitudinal decline in these parameters also, but it is possible that this effect is more subtle and additional data are required before we can detect it.

While the association between speaking rate and the IVs fails to reach statistical significance, there are some trends in the data that merit further exploration. Consistent with the longitudinal analysis, there seems to be a relationship between age and speaking rate, but additional data may be required to detect it at $\alpha = 0.05$. There may also be a trend between speaking rate and some of the fight parameters that could reach statistical significance if additional data were available. For example, there seems to be an inverse trend between the number of rounds in the last fight and speaking rate, and a positive trend between the number of days since the last fight and speaking rate. Both of these are reasonable, however neither reaches statistical significance. The ways in which speaking rate and pitch/loudness variation differ with regard to these parameters are intriguing. Pitch and loudness range are closely related to motor disturbances, but speaking rate, on the other hand, could

Table 2: *Multivariate regression results for pitch range, loudness range, and speaking rate.*

Pitch Range			
Variable	Beta	t	p
Age	-0.342	-1.384	0.196
Rounds	0.322	1.201	0.257
Jabs landed	-0.065	-0.272	0.791
Power landed	-0.216	-0.790	0.448
# of days since last fight*	0.675	3.358	0.007
Loudness Range			
Variable	Beta	t	p
Age	0.292	1.082	0.305
Rounds	-0.037	-0.127	0.901
Jabs landed	-0.282	-1.083	0.304
Power landed	-0.034	0.114	0.912
# of days since last fight*	0.698	3.189	0.010
Speaking Rate			
Variable	Beta	t	p
Age	-0.517	-2.145	0.058
Rounds	-0.452	-1.727	0.115
Jabs landed	-0.221	-0.949	0.365
Power landed	0.181	0.678	0.513
# of days since last fight	0.250	1.276	0.231

also be detecting increased difficulty in word-finding abilities through longer pauses. This could explain the observed difference but requires a prospective study for evaluation.

4. Conclusions

In this paper we analyze publicly available interviews from legendary boxer Muhammad Ali and measure aspects of speech production expected to change with parkinsonism, before he was diagnosed with the disease. We measure speaking rate, pitch range, loudness range, and vowel space area from the data. The results reveal that Mr. Ali’s speaking rate sharply declined over time as did his ability to clearly articulate vowels. A multivariate analysis further reveals a relationship between the number of days that elapsed since the last boxing match that Ali participated in and the intonational variability of his speech patterns. The results have implications in a number of domains. The multivariate analysis reveals that some of the speech characteristics could an important component in a “return to play” battery. Both loudness range and pitch range were associated with the number of days since the last fight. These easy-to-estimate parameters could provide a means of monitoring the progress of athletes in high-impact sports to determine recovery. More broadly, the results provide some evidence that longitudinal analysis of conversational speech under different settings can be used to detect early signs of a neurological disorder. While the data was analyzed over a range that spanned a decade, this timeline may be shortened if additional modalities are used (e.g. accelerometer data from phone) and if the speech data is subsampled to account for context, recording conditions, etc. This could have implications for the development of mobile applications that passively monitor speech and provide indicators of neurological decline.

5. Acknowledgements

The authors gratefully acknowledge partial support of this work by an NSF STTR Phase I grant awarded to Aural Analytics, LLC and an NIH-NIDCD Grant 1R21DC013812.

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