Words Spoken Daily among Individuals with Neurodegenerative Conditions: A Pilot Study

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KEY POINTS

Question: Do individuals with neurodegenerative conditions speak fewer words daily?

Findings: In this pilot, cross-sectional study, we applied machine learning algorithms to data collected by a simple recording device worn around the neck to quantify the number of words 34 individuals spoke over a single day. Individuals with Parkinson's disease (6934 words daily) and with mild cognitive impairment or early Alzheimer's disease (6727 words) may speak fewer words than age-matched controls (12,116 words).

Meaning: The number of words spoken daily can be quantified and could be a useful measure of cognitive function.

ABSTRACT

Importance: The number of steps taken daily is a simple, powerful measure of physical function in the real world. Similar measures of cognitive function are generally lacking.

Objective: To determine whether we could quantify the number of words individuals speak daily and to see if individuals with neurodegenerative disorders speak less than those without such conditions.

Design: A cross-sectional, pilot study.

Setting: Participants were recruited from academic neurology and memory disorder clinics and underwent baseline cognitive assessments in clinic from June 2019 to February 2020 and then wore a simple recording device around their neck during the waking day in their natural setting.

Participants: Individuals with clinical or biomarker verified diagnoses of Parkinson's disease, mild cognitive impairment or early Alzheimer's disease, and age-matched controls.

Main Outcome and Measure: The number of words participants spoke over the course of a day as quantified by machine learning algorithms.

Results: Data from a single day of recording from 34 of 35 participants were suitable for analysis including 14 with Parkinson's disease (mean [SD] age, 67.0 [5.8] years; 7 [50.0%] women), six with mild cognitive impairment or early Alzheimer's (mean [SD] age, 77.7 [8.0] years; 4 [66.7%] women), and 14 without a neurodegenerative condition (mean [SD] age, 72.5 [8.7] years; 6 [42.9%] women). Individuals with Parkinson's disease (mean=6934 words daily, 95% CI: 2460 to 11,408; P=0.10) and with mild cognitive impairment or early Alzheimer's disease (6727 words daily, 95% CI: 0 to 13,561; P=0.19) spoke numerically but not significantly fewer words than age-matched controls (12,116 words spoken daily, 95% CI: 7642 to 16,590).

Conclusions and Relevance: In a small feasibility pilot study, the number of words an individual spoke daily could be quantified and may be less among individuals with a neurodegenerative disorder than

age-matched controls. This potentially useful measure of cognitive function is worthy of further investigation.

INTRODUCTION

The number of steps taken daily is a powerful measure of physical health[1]. By contrast, the number of words an individual speaks daily has been little studied. Verbal fluency is diminished in many neurodegenerative disorders, including Parkinson's disease, mild cognitive impairment, and Alzheimer's disease [2]. In a small pilot study, we sought to determine whether we could use a simple recording device and machine learning algorithms to quantify the number of words an individual speaks in a day. We then compared the number of words individuals with a neurodegenerative condition spoke in a day to age-matched controls.

METHODS

Study design

In this observational study, individuals with clinical or biomarker verified diagnoses[3] of Parkinson's disease, mild cognitive impairment, early Alzheimer's disease, or without a neurodegenerative disorder were recruited from clinics. At a baseline visit, participants completed the Montreal Cognitive Assessment[4], Controlled Word Association Test[5], Animal Naming Test[6] and Boston Naming Test[7] and were provided a small audio recording device (aTTo mini-module voice recorder) that could be worn around the neck with an adjustable lanyard. Participants read a standard passage for five to ten minutes in clinic and then went home with instructions to wear the device during waking hours for six days. Participants completed the same cognitive battery six months later and were asked to wear the device again for six days. This analysis was restricted to the baseline assessments. Participants were compensated for their time, and the study was reviewed and approved by the institutional review board at the University of Rochester.

Analysis

The recorded speech was analyzed in four stages (**Figure 1**). In the first stage, we computed a "voiceprint," a feature analogous to a fingerprint that uniquely identifies the speaker, based on the participant's reading of the selected passage.

In the second stage, we selected one day to analyze. First we evaluated which days had at least six hours of recording. Additionally, any days with extremely noisy events (e.g., concerts) were eliminated. From this set of days, we listened to 30 seconds every 15 minutes and selected the day with the fewest interferences from sounds (e.g., television, radio).

In the third stage, we developed a deep neural network-based speaker identification model[8] to extract recording segments when each participant spoke. The neural network consisted of a convolutional layer-based feature encoder and a fully connected layer-based feature aggregator and was trained on a large-scale speech dataset[9]containing over 7000 speakers. To increase the model's robustness, we added noise from a dataset[10] that contains urban environmental noises with different signal-to-noise ratios distributed between –10 to 22 dB. After training the model, we computed a reference voiceprint using a 50-second portion of the clinic's reference and at-home test recordings that were segmented into one-second segments with a hop size of 20 ms. One feature vector was computed from each segment, and their average was used as the final reference voiceprint. We then computed a recording's cosine similarity with the reference voiceprint. We identified segments as the participant's speech that had a cosine similarity higher than a threshold, which was tuned to maximize the F1-score on a 2-minute validation recording that was manually annotated. Finally, we concatenated all segments identified as the participant's speech into a single recording for analysis.

In the fourth stage, we used the Amazon Web Services Transcribe tool and the Python Natural Language Toolkit[11] to transcribe the extracted speech into individual words that could be counted. We

compared the mean number of words spoken daily by individuals with each of the neurodegenerative conditions to age-matched controls using an analysis of variance.

RESULTS

Between June 2019 and February 2020, we recruited 39 participants, completed baseline visits for 35 individuals, and were able to analyze the number of words spoken in one day from 34 participants. Because only one participant had early Alzheimer's disease, this individual was grouped with those with mild cognitive impairment. Fourteen had Parkinson's disease, six had either early Alzheimer's disease or mild cognitive impairment, and 14 were age-matched controls without a neurodegenerative disorder. Their baseline characteristics are summarized in **Table 1**.

The average duration of recording time was 12.8 hours (12.4 hours for Parkinson's disease; 12.0 hours for early Alzheimer's/mild cognitive impairment; 13.5 hours for age-matched controls). As shown in **Figure 2**, on average individuals with Parkinson's disease (6934 words daily, 95% CI: 2460 to 11,408; P=0.10) and with early Alzheimer's disease or mild cognitive impairment (7181 words daily, 95% CI: 0 to 13,561; P=0.19) tended to speak less than age-matched controls (12,116 words spoken daily, 95% CI: 7642 to 16,590). In each group, the number of words spoken daily was highly variable.

DISCUSSION

In this proof-of-concept study, the number of words individuals with and without a neurodegenerative disorder could be quantified and may be less among those with Parkinson's disease or early Alzheimer's disease or mild cognitive impairment. While multiple studies have quantified physical health using the number of steps an individual takes, few have sought to assess cognitive function by counting the number of words spoken daily. One study from *Science* of college students found that women (16,215 words daily) and men (15,669) spoke about the same number of words daily[12]. Another small study in

Parkinson's disease found that the speaking rate (words per minute) was similar to that of age-matched controls[13]. One more found that individuals with mild cognitive impairment spoke more words than those with normal cognition during a 30-minute conversation[14].

A simple, objective, real-world measure of cognition could have important applications. First, the number of words an individual speaks, or changes in that number, could be an early signal of cognitive impairment and facilitate a timely diagnosis. Second, such a measure could be used to track disease progression. Third, an objective, real-world metric could help gauge the effectiveness of interventions, including experimental therapies, and supplement the current rating scales that are subjective, categorical, and expert-dependent[15]. Fourth, this measure could be applied across a wide range of neuropsychiatric conditions where verbal fluency is impaired.

This pilot study has significant limitations. The study population was small, drawn from a single institution, and relatively homogenous. The analysis was limited to a single day and based on selection criteria. Thus, it may not be representative of a participant's actual cognitive function. The number of words an individual speaks is likely to be highly variable and dependent upon the environment (work versus home), the day of the week, the number of people they encounter, the weather, and many other factors. A larger sample size with more days of recording would help determine whether the differences observed here are generalizable. This study required significant manual checking of recording quality and threshold tuning, which would limit larger scale applications. Finally, the results reported here are cross-sectional. Longitudinal studies will help inform the rate of change in this measure and its association with disease progression.

The number of individuals with dementia is rising rapidly domestically and globally. Real-world objective measures of cognitive impairment could improve diagnosis, care, and therapeutic development. In this study, novel applications of machine learning to recorded speech quantified the

number of words spoken daily and suggested that this number may be lower in those with a neurodegenerative condition.

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Concept and design: Hasselberg, Masino, Duan, Dorsey

Acquisition, analysis, or interpretation of data: All authors

Drafting of the manuscript: Zhang, Zhu, Soto, Lettenberger, Masino, Dorsey

Critical revision of the manuscript for important intellectual content: All authors

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Data Sharing Statement: Due to the private nature of the data collected, the data from this study will not be shared.

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Figure 1. Overview of analytical approach to quantifying the number of words spoken in a day

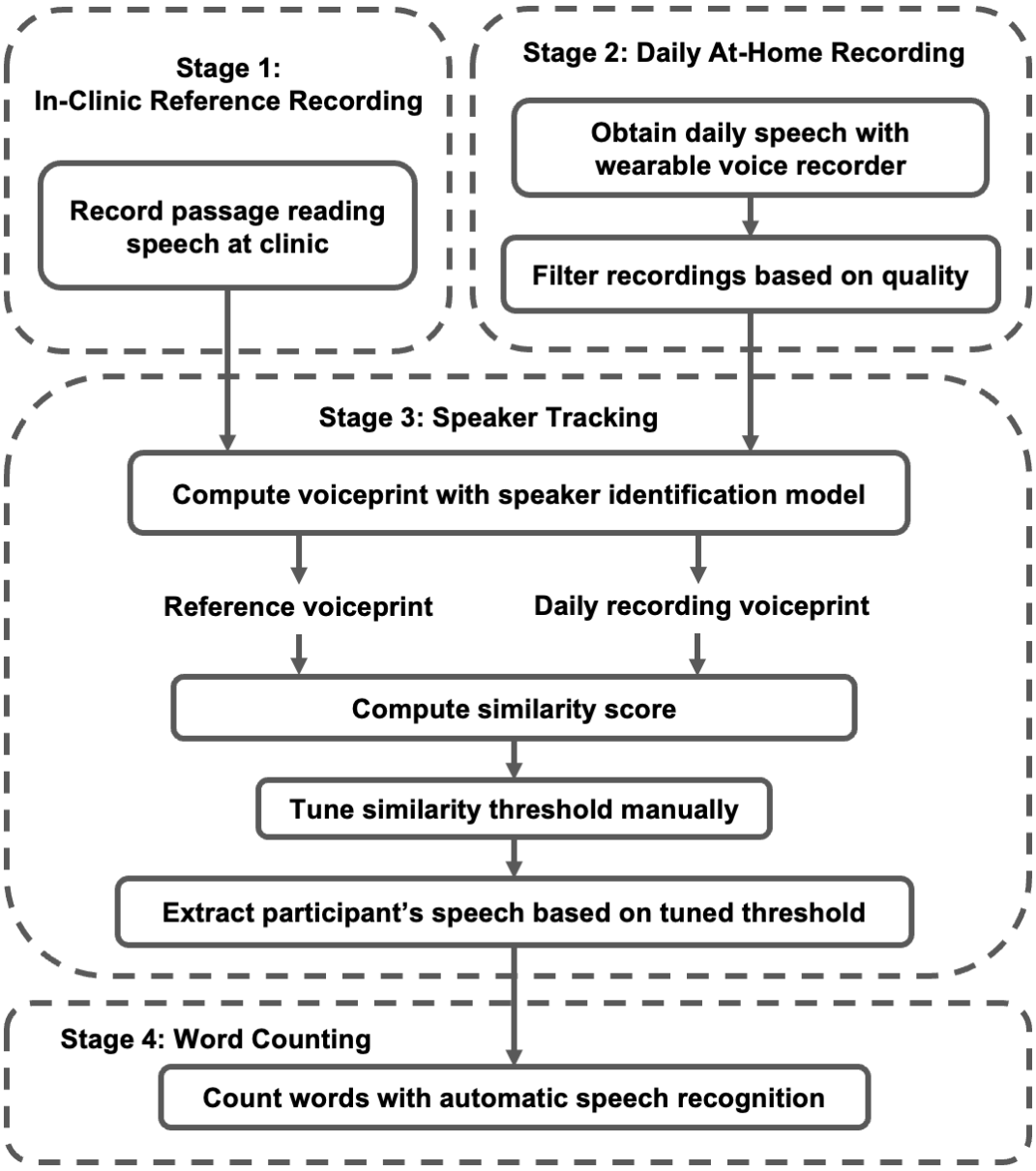

Table 1. Baseline demographics and clinical characteristics of the study participants

	Parkinson's disease (n=14)	Early Alzheimer's disease or mild cognitive impairment (n=6)	Age-matched controls (n=14)
Demographics			
Sex			
Female	7 (50)	4 (67)	6 (43)
Male	7 (50)	2 (33)	8 (57)
Age, y	67.0 (5.8)	77.7 (8.0)	72.5 (8.7)
Race			
White	14 (100)	6 (100)	14 (100)
American Indian or Alaska Native	1 (7)	0	0
Education			
Doctorate/professional school degree	1 (7)	1 (17)	1 (7)
Master's degree	2 (14)	1 (17)	4 (29)
Bachelor's degree	7 (50)	2 (33)	5 (36)
Associate's degree, some college	3 (21)	1 (17)	3 (21)
High school diploma	1 (7)	1 (17)	1 (7)
Employment status			
Retired	13 (93)	5 (83)	10 (71)
Disabled	1 (7)	0	1 (7)
Homemaker	0	0	1 (7)
Part-time	0	1 (17)	1 (7)
Full-time	0	0	1 (7)
Living situation			
Private home	13 (93)	4 (67)	13 (93)
Independent living facility	0	1 (17)	0
Assisted living facility	0	1 (17)	1 (7)
Skilled nursing facility	1 (7)	0	0
Lives with pet(s)	11 (79)	3 (50)	9 (64)
Lives with at least one other person	14 (100)	6 (100)	14 (100)
Clinical characteristics			
Montreal Cognitive Assessment	27.6 (1.8)	22.0 (2.8)	27.8 (1.4)
Controlled Word Association Test-FAS	45.6 (11.8)	31.0 (9.4)	39.9 (16.7)
Boston Naming Test	56.2 (7.8)	46.7 (13.9)	58.6 (2.2)
Animal Naming Test	21.3 (5.6)	10.2 (2.6)	19.7 (4.2)
Age at diagnosis, y	58.9 (6.7)	74.8 (7.3)	NA
Disease duration, y	8.1 (4.5)	2.7 (2.2)	NA
Charlson Comorbidity Index > 0	4 (29)	5 (83)	5 (36)
Depression diagnosis	7 (50)	3 (50)	0
Anxiety diagnosis	2 (14)	3 (50)	1 (7)

Data are reported as number (percentage) or mean (standard deviation).

Figure 2. Number of words spoken in one day among individuals with Parkinson's disease, early Alzheimer's disease/mild cognitive impairment, and age-matched controls