ELSEVIER

Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring 1 (2015) 112–124

Alzheimer's & Dementia

Automatic speech analysis for the assessment of patients with predementia and Alzheimer's disease

Alexandra König[a,b,*], Aharon Satt[c], Alexander Sorin[c], Ron Hoory[c], Orith Toledo-Ronen[c], Alexandre Derreumaux[a], Valeria Manera[a], Frans Verhey[b], Pauline Aalten[b], Phillipe H. Robert[a,d], Renaud David[a,d]

[a]*Research Unit CoBTeK - Cognition Behaviour Technology, Edmond & Lily Safra Research Center, University of Nice Sophia Antipolis, Nice, France*
[b]*Alzheimer Centre Limburg, Maastricht University Medical Center, School for Mental Health and Neuroscience, Maastricht, The Netherlands*
[c]*Speech Technologies, IBM Research, Haifa, Israel*
[d]*Centre Mémoire de Ressources et de Recherche, CHU de Nice, Nice, France*

Abstract

Background: To evaluate the interest of using automatic speech analyses for the assessment of mild cognitive impairment (MCI) and early-stage Alzheimer's disease (AD).
Methods: Healthy elderly control (HC) subjects and patients with MCI or AD were recorded while performing several short cognitive vocal tasks. The voice recordings were processed, and the first vocal markers were extracted using speech signal processing techniques. Second, the vocal markers were tested to assess their "power" to distinguish among HC, MCI, and AD. The second step included training automatic classifiers for detecting MCI and AD, using machine learning methods and testing the detection accuracy.
Results: The classification accuracy of automatic audio analyses were as follows: between HCs and those with MCI, 79% ± 5%; between HCs and those with AD, 87% ± 3%; and between those with MCI and those with AD, 80% ± 5%, demonstrating its assessment utility.
Conclusion: Automatic speech analyses could be an additional objective assessment tool for elderly with cognitive decline.

Keywords: Dementia; Alzheimer's; Mild cognitive impairment; Speech analyses; Assessment; Information and communication technology (ICT); Audio; Vocal task

1. Introduction

Various types of dementia affect human speech and language [1] and disorders or irregularities in the language domain could be a strong predictor of disease progression [2,3]. Considering this association, reason exists to explore speech analysis as a method for early dementia diagnosis. One avenue we investigated was the analysis of speech using software that takes as input the audio recording from a clinical consultation. Combined with other methods such as video monitoring [4] and actigraphy [5], the speech analysis tool has the potential to become a useful, noninvasive, and simple method for early dementia diagnosis [6]. These technologies enable rapid, accurate, and inexpensive monitoring over time. Noninvasive diagnosis methods will also reduce the burden on the healthcare system and improve the possibility of early dementia detection.

Alzheimer's disease (AD) is diagnosed when it has reached the stage at which cognitive (i.e., episodic memory impairment) and neuropsychiatric symptoms interfere with social functioning or activities of daily living. In addition to the clinical criteria, Dubois et al [7] recently suggested that pathophysiologic biomarker evidence is also needed. The dementia diagnosis is strongly based on clinical judgment, for which appropriate assessment instruments are of vital importance. Providing reliable additional methods to

*Corresponding author. Tel.: +33-65-202-1156; Fax: +33-49-352-9257.
E-mail address: a.konig@maastrichtuniversity.nl

http://dx.doi.org/10.1016/j.dadm.2014.11.012

assess dementia progression in patients is of high interest, because the cognitive domains other than memory have been increasingly recognized as important outcome measures in clinical practice. Information and communication technology (ICT), in particular, automatic speech analysis, is important, because it enables the capture of patient performance and actions to accurately evaluate patients in real time. Using real life situations and applying less intrusive methods that do not require specialized personnel would also be advantageous.

Speech analyses have already been used in patients with dementia [8–10] and those with Parkinson's disease [11] to find potential vocal markers. Studies have shown that one consistently found language abnormality in early AD is anomia, or impaired word finding [12,13], leading to circumlocution that is evidenced in poor word list generation, in particular, for words in a given semantic category [14]. Patients with AD have difficulty accessing semantic information intentionally, which manifests itself in a manner that appears to reflect a general semantic deterioration [1].

This difficulty can affect the temporal cycles during spontaneous speech production (speech fluency) and therefore can be detectable in the hesitation and uttering of a patient [15]. Additional affected speech characteristics in patients with AD seem to be those related to articulation (speed in language processing) [16], prosody in terms of temporal and acoustic measures, which includes alterations in rhythm (ability to vary pitch level, pitch modulation, reduced or fluctuating rate of language output, frequent word finding pauses, a lack of initiative, and slowness) [17,18], and eventually, in later stages, phonologic fluency [19]. Some of these characteristic alterations could be detected by automatic analysis by extracting speech parameters from patients, for example, by performing cognitive vocal tasks or even recording free speech.

Recently, Ahmed et al [2] tried to identify the features of speech that could be used to examine the longitudinal changes to profile impairment in patients with AD. Their study showed that progressive disruption in language integrity was detectable as early as the prodromal stage. Meilan et al [20] found that voiceless segments explained a significant portion of the variance in the overall scores obtained in the neuropsychological test. López-de-Ipiña et al [21] investigated the potential of applying artificial intelligence algorithms to patients' speech as a method to improve the diagnosis of AD and determine the degree of its severity, with promising results for early diagnosis and classification of patients with AD. Roark et al [22] studied different characteristics of spoken language that were automatically derived, such as pause frequency and duration. They demonstrated statistically significant differences between healthy subjects and subjects with mild cognitive impairment (MCI) for a number of measures. However, in these studies, the expected performance of an end-to-end voice-based dementia assessment system was not clearly demonstrated and was often limited by the sample size, method (i.e., manual transcriptions), and technologies.

The present study aimed to determine the value of automatic analyses of voice recordings during vocal tasks for the early diagnosis of AD. This was done through the Dem@Care project, a substudy of the European Community FP7 program. Within this project, ICTs are used for the assessment of patients with dementia in an ecological setting [23]. Specialized IBM speech researchers worked together in close collaboration with the clinical dementia researchers to develop a process to analyze automated speech recordings. To detect dementia-related characteristics in human voice and speech patterns, a classifier was developed using a support vector machine to analyze the statistical properties of vocal features [24]. The classifier determined which features characterize different states of the disease. The main research objective was to determine whether automated speech and voice pattern analyses increases the accuracy, reliability, and affordability of AD early detection.

The present study analyzed voice recordings collected during cognitive vocal tasks performed by patients with AD, MCI, and healthy elderly controls (HCs). The tasks were used to determine the effectiveness of speech processing technologies to support dementia assessment. The primary objective of the study was to investigate whether a method based on automatic speech analyses can detect differences among AD, MCI, and HC subjects. Furthermore, we sought to determine which speech features are the most sensitive to the deterioration due to the disease. This would allow us to obtain a profile for the different populations to improve the differential diagnosis. The secondary objective was to evaluate which tasks are the most appropriate ones to allow the detection of differences in these speech features.

2. Methods

2.1. Participants

Within the framework of the Dem@care project, speech recordings were conducted at the Memory Clinic in Nice, France. The Nice ethics committee approved the present study. Each participant gave informed consent before the first assessment. Participants aged 65 years or older were recruited through the Memory Clinic located at the geriatric department of the University Hospital.

2.2. Clinical assessment

The general cognitive status was assessed using neuropsychological tests, including the

- Mini-mental state examination (MMSE) [25]
- Five word test [26]
- Frontal assessment battery [27]
- Instrumental activities of daily living scale [28]

Additionally, neuropsychiatric symptoms were assessed using the neuropsychiatric inventory [29]. Apathy was