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Towards automated electroencephalography-based Alzheimer's disease diagnosis using portable low-density devices

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ABSTRACT

Today, Alzheimer's disease (AD) diagnosis is carried out using subjective mental status examinations assisted in research by scarce and expensive neuroimaging scans and invasive laboratory tests; all of which render the diagnosis time-consuming, geographically confined and costly. Driven by these limitations, quantitative analysis of electroencephalography (EEG) has been proposed as a non-invasive and more convenient technique to study AD. Published works on EEG-based AD diagnosis typically share two main characteristics: EEG is manually selected by experienced clinicians to discard artefacts that affect AD diagnosis, and reliance on EEG devices with 20 or more electrodes. Recent work, however, has suggested promising results by using automated artefact removal (AAR) algorithms combined with medium-density EEG setups. Over the last couple of years, however, low-density, portable EEG devices have emerged, thus opening the doors for low-cost AD diagnosis in low-income countries and remote regions, such as the Canadian Arctic. Unfortunately, the performance of automated diagnostic solutions based on low-density portable devices is still unknown. The work presented here aims to fill this gap. We propose an automated EEG-based AD diagnosis system based on AAR and a low-density (7-channel) EEG setup. EEG data was acquired during resting-awake protocol from control and AD participants. After AAR, common EEG features, spectral power and coherence, are computed along with the recently proposed amplitude-modulation features. The obtained features are used for training and testing of the proposed diagnosis system. We report and discuss the results obtained with such system and compare the obtained performance with results published in the literature using higher-density EEG layouts.

1. Introduction

The term dementia is used to encompass a number of neurodegenerative diseases and conditions that have their origin in damage and death of neurons. Among the different diseases classified as dementia, Alzheimer's disease (AD) is the most frequent, accounting for 60–80% of dementia cases worldwide. AD is a chronic neurodegenerative disorder that causes decay in the number of synapses and eventual death of neurons. This process may begin 20 or more years before behavioural symptoms appear. At early stages of AD, these brain changes do not affect individual's life style. The progression of AD leads to a decline and, consequentially, loss of both cognitive (e.g., memory, reasoning, communication) and behavioural functions that interfere with the individual's daily life. In the final stages of the disease, the individual requires round-the-clock care. AD is ultimately fatal [1,2].

Studies show that in 2013 44.4 million people were suffering from dementia worldwide, and this number is projected to grow to 75.6 million by 2030 and to 135.6 million by 2050. Because of the increased life expectancy around the world, most of the dementia cases (approximately 70%) will take place in low- and middle-income countries, as depicted in Fig. 1. AD not only affects individuals but also their families whom become caregivers as the pathology progress. Moreover, the economic impact of dementia represents a great toll on society. For example, in 2010 the global annual cost for dementia care was estimated at US$604 billion, i.e.

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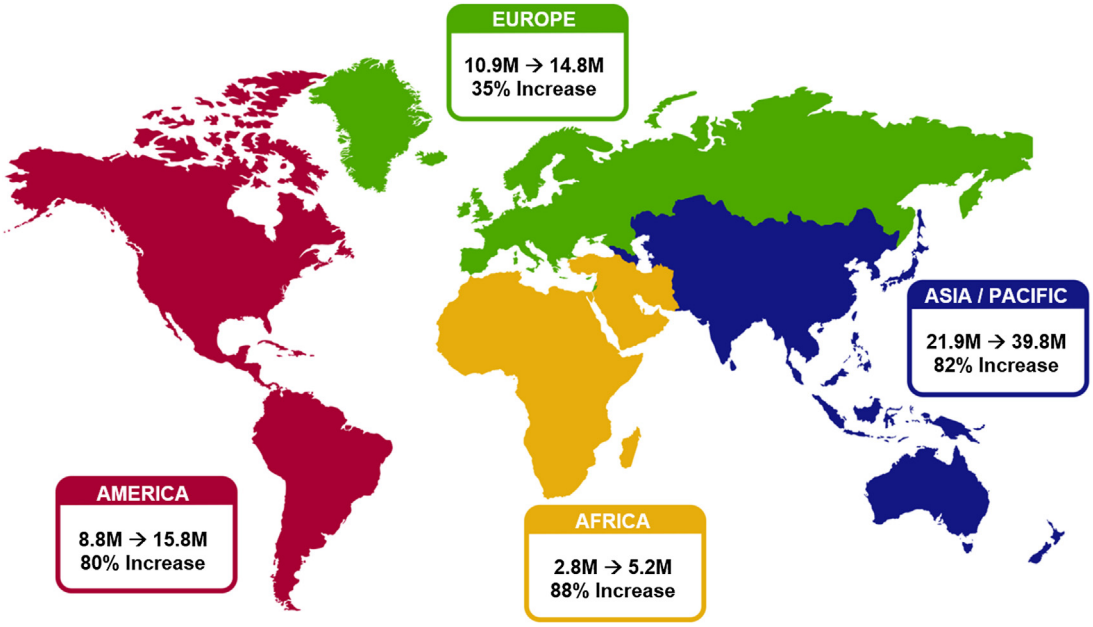

Fig. 1. Global dementia incidence in 2013 and projected increase by 2030.

twice the Exxon Mobil revenue for the same year, and it is expected to increase by 85% by the year 2030 [2,3].

Due to the serious implications of current and future global number of dementia cases, the World Health Organization has made an urgent call to include dementia in the public health agenda of each country, with the objective of improving (early) diagnosis and providing better care and support for patients, their families, and caregivers [1].

Despite the fact that today there are no treatments to cure or alter the progression of AD, an accurate and early diagnosis empowers AD patients and their families to learn about the disease, look for palliative therapies, deal with financial and legal decisions, carry out housing and healthcare arrangements, look for support community groups, and actively promote AD awareness and research [2]. Moreover, novel disease-modifying drugs are being studied and developed around the world, and it is likely that their efficacy will be higher in early stages of AD [4], thus making early diagnosis a pivotal element in AD research and therapy.

Nowadays, AD diagnosis is performed following the criteria of the Diagnostic and Statistical Manual of Mental Disorders, either fourth edition (DSM-IV-TR) or fifth edition (DSM-5), the National Institute of Neurological Disorders and Stroke and Alzheimer Disease and Related Disorders (NINCDS–ADRDA) Work Group, and neurophysiological tests as the Mini-Mental State Evaluation (MMSE) [5]. In research, these criteria are commonly assisted by biomarkers obtained through structural neuroimaging with magnetic resonance imaging (MRI) and/or molecular neuroimaging with positron emission tomography (PET), by methods that aim at finding tissue damage in specific structures of the brain, and/or by cerebrospinal fluid analysis with the objective of finding AD-related compounds.

AD diagnosis based on the former criteria leads to accuracies ranging from 85 to 95%, and relies on experienced clinicians, meticulous and exhaustive testing sessions, as well as costly and scarce neuroimaging tools and invasive procedures [6]. Unfortunately, definite AD diagnosis is only confirmed through post-mortem examination of brain tissue. These constraints limit the implementation of early AD diagnosis in low-income countries, remote and rural regions, as well as in metropolitan areas where wait times for non-emergency MRIs can be in the order of months [7], thus making quantitative electroencephalography (qEEG, henceforth referred to as EEG) a promising tool for Alzheimer's disease diagnosis.

Over the last few decades, quantitative electroencephalography has been successfully utilized as a reliable technology for the study and diagnosis of cortical disorders. EEG signals consist of recordings of changes in the electric potential measured at the scalp; these changes have their origin in the electrical activity evoked by the neurons synchronized firing in the cerebral cortex. Therefore, the EEG signal provides a global snapshot of the underlying brain activity. The commonly used "international 10-20 system" electrode layout, is depicted in Fig. 2a, and the acquired EEG signals are presented in Fig. 2b. For analysis, EEG signals are generally divided into 5 major frequency bands, namely: delta (δ) 0.1–4 Hz, theta (θ) 4–8 Hz, alpha (α) 8–12 Hz, beta (β) 12–30 Hz and gamma (γ) >30 Hz [8]. Fig. 2c shows an EEG signal from one electrode decomposed into its major component bands. It is common to represent the EEG signals and their major bands in the frequency domain, as depicted by Fig. 2d. Unlike other biopotentials (such as the electrocardiographic signals), EEG signals are rarely analysed by the naked eye, thus further processing is required to identify patterns and extract valuable information form EEG recordings.

EEG represents a non-invasive and inexpensive technique for the study of neurodegenerative disorders. Thus, it has emerged as an interesting tool for the study and diagnosis of AD. While traditional EEG devices are expensive and hard to transport, advances in the manufacturing of electronic devices have led to the recent appearance of affordable portable wireless EEG devices, opening the doors to EEG-based AD diagnosis in developing countries and geographically remote regions.

The ultimate aim of this paper is to propose and discuss the development and performance of an automated EEG-based AD diagnosis system relying in portable EEG devices. In order to achieve this goal, the next section will present relevant aspects of EEG-based AD diagnosis, placing emphasis on the existing challenges that arise with the use of portables EEG devices.

2. EEG-based AD diagnosis

Since EEG signals reflect functional changes in the cerebral cortex, they can be used to infer neuronal degeneration and decay