Please cite this article in press as: Gorji HT, Haddadnia J. A novel method for early diagnosis of Alzheimer's disease based on pseudo Zernike moment from structural MRI. Neuroscience (2015), http://dx.doi.org/10.1016/j.neuroscience.2015.08.013

Neuroscience xxx (2015) xxx–xxx

A NOVEL METHOD FOR EARLY DIAGNOSIS OF ALZHEIMER'S DISEASE BASED ON PSEUDO ZERNIKE MOMENT FROM STRUCTURAL MRI

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Abstract—Alzheimer's disease (AD) is a progressive neurodegenerative disorder and the most common type of dementia among older people. The number of patients with AD will grow rapidly each year and AD is the fifth leading cause of death for those aged 65 and older. In recent years, one of the main challenges for medical investigators has been the early diagnosis of patients with AD because an early diagnosis can provide greater opportunities for patients to be eligible for more clinical trials and they will have enough time to plan for future, medical and financial decisions. An established risk factor for AD is mild cognitive impairment (MCI) which is described as a transitional state between normal aging and AD patients. Hence an accurate and reliable diagnosis of MCI can be very effective and helpful for early diagnosis of AD. Therefore in this paper we present a novel and efficient method based on pseudo Zernike moments (PZMs) for the diagnosis of MCI individuals from AD and healthy control (HC) groups using structural MRI. The proposed method uses PZMs to extract discriminative information from the MR images of the AD, MCI, and HC groups. Two types of artificial neural networks, which are based on pattern recognition and learning vector quantization (LVQ) networks, were used to classify the information extracted from the MRIs. We worked with 500 MRIs from the database of the Alzheimer's Disease Neuroimaging Initiative (ADNI 1 1.5T). The 1 slice of 500 MRIs used in this study included 180 AD patients, 172 MCI patients, and 148 HC individuals. We selected 50 percent of the MRIs randomly for use in training the classifiers, 25 percent for validation and we used 25 percent for the testing phase. The technique proposed here yielded the best overall classification results between AD and MCI (accuracy 94.88%, sensitivity 94.18%, and specificity 95.55%), and for pairs of the MCI and HC (accuracy 95.59%, sensitivity 95.89% and specificity 95.34%). These results were achieved using maximum order 30 of PZM and the pattern recognition network with the scaled conjugate gradient (SCG) back-propagation training algorithm as a classifier. © 2015 Published by Elsevier Ltd. on behalf of IBRO.

Key words: Alzheimer's disease, mild cognitive impairment, healthy control, magnetic resonance images, pattern recognition network, learning vector quantization.

INTRODUCTION

Dementia is a general term for diseases and conditions that develop when nerve cells in the brain die or no longer function normally. The most common type of dementia is Alzheimer's disease (AD) (Budson and Solomon, 2011) a progressive neurodegenerative disease (Braak and Braak, 1991). The disease is associated with impaired consciousness and memory loss, and it generally occurs in people aged over 65 (Brookmeyer et al., 1998). The disease was first described by German psychiatrist Alois Alzheimer in 1906 (Berchtold and Cotman, 1998). The incidence of AD and other dementia-related disease has been increasing rapidly each year throughout the world. For example, approximately 4.7 million Americans had AD in 2010, and this number had increased to 5.3 million in 2013. It has been estimated that there will be 13.8 million AD patients in the U.S. by 2050 (Hebert et al., 2013). There were 68% more deaths from AD in 2010 than there were in 2000, making AD the sixth leading cause of death in the U.S. (Hebert et al., 2001; Escudero et al., 2011).

In 2012, the National Institute of Aging and the Alzheimer's Association proposed new criteria and guidelines for describing and categorizing the changes in the brain associated with AD and other dementia-related diseases (Hyman et al., 2012). These criteria define the three stages of AD as pre-clinical AD, mild cognitive impairment (MCI) due to AD, and dementia due to AD. MCI is described as a transitional state between normal aging and AD patients, and people with MCI exhibit difficulties with memory or thinking, but the impairment is not severe enough to affect their ability to conduct their daily activities (Petersen et al., 1999). In the new criteria and guidelines that were proposed in 2011 (Albert et al., 2011; McKhann et al., 2011; Sperling et al., 2011) MCI is actually an early stage of Alzheimer's or other dementia-related diseases. Approximately 50% of the people who see a doctor concerning the symptoms of MCI symptoms will develop dementia in three to four years (Petersen et al., 1999). Therefore, the ability to

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Abbreviations: AD, Alzheimer's disease; ADNI, Alzheimer's disease Neuroimaging Initiative; GM, gray matter; HC, healthy control; LVQ, learning vector quantization; LVQNN, Learning Vector Quantization neural network; MCI, mild cognitive impairment; MRI, magnetic resonance imaging; PET, positron emission tomography; PZMs, pseudo Zernike moments; ROI, regions of interest; SBA, surface-based analysis; SCG, scaled conjugate gradient; VBM, voxel-based morphometry; ZMs, Zernike moments.

http://dx.doi.org/10.1016/j.neuroscience.2015.08.013
0306-4522/© 2015 Published by Elsevier Ltd. on behalf of IBRO.

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diagnose and classify MCI from AD patients and HC groups precisely will be very effective and helpful for the early diagnosis of AD. In recent years, several neuroimaging techniques have been used in the clinical diagnosis and classification of AD patients, MCI patients, and healthy individuals. These techniques include computed tomography (CT), magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and single-photon emission computed tomography (SPECT), and several attempts have been made to prove and compare the efficiency and reliability of these techniques (Erkinjuntti et al., 1989; Toyama et al., 2005; Davatzikos et al., 2008; Chaves et al., 2009; Magnin et al., 2009; Cuingnet et al., 2011; Illán et al., 2011; Tripoliti et al., 2011; Ortiz et al., 2013). Usually, researchers use three types of well-known techniques for diagnosing and classifying the AD, MCI, and HC groups. Some previous studies were based on volumetric measurements of segmented regions of interest (ROI), (Convit et al., 1997, 2000; Kaye et al., 1997; Rusinek et al., 2004; Tapiola et al., 2008) such as the hippocampus, entorhinal cortex, and gray matter (GM) in some regions that are affected by AD. Several investigators have proposed the use of Voxel-based Morphometry (VBM) for measuring the spatial distribution of atrophy in the white matter (WM) and GM of the brain as well as in the cerebrospinal fluid (CSF) in MCI and AD patients (Hämäläinen et al., 2007; Guo et al., 2010; Shin et al., 2010; Kim et al., 2011; Li et al., 2012), whereas other groups use cortical thickness as a feature for diagnosing AD, MCI, and HC (Lerch et al., 2008; Hua et al., 2009; McDonald et al., 2009; Lehmann et al., 2011; Grand'Maison et al., 2013).

For many years, moments have been used as descriptors of the properties of the images in pattern recognition, and many researchers still use them in several applications.

Zernike moments (ZMs) have attracted extensive attention as a powerful feature extractor in pattern recognition due to their high robustness to noise and their good performance in recognizing circular shapes, such as faces (Jenkinson et al., 2005). ZMs can be used to extract structural facial features that are local features of face images, for example, the shapes of eyes, nose and mouth in human face images. Since Zernike polynomials are orthogonal to each other, ZMs can represent the properties of an image with no redundancy or overlap of information between the moments, so they are used extensively in various applications (Haddadnia et al., 2003; Li et al., 2009; Liyun et al., 2009; Tahmasbi et al., 2011).

Although the ZMs are very useful in image processing, they have some limitations. Thus, an improved version was developed, which is referred to as pseudo Zernike moment (PZM).

Current research is directed toward the development of a novel method for early diagnosis of AD based on PZM's extraction of features of AD, MCI, and HC from MR images. In this study, we used pattern recognition and learning vector quantization (LVQ) networks as classifiers to discriminate between the three groups.

MATERIALS

Data

Data used in the preparation of this paper were obtained from the Alzheimer's disease Neuroimaging Initiative (ADNI) database (http://www.loni.ucla.edu/ADNI). The ADNI was launched in 2003 by the National Institute on Aging (NIA), the National Institute of Biomedical Imaging and Bioengineering (NIBIB), the Food and Drug Administration (FDA), private pharmaceutical companies and non-profit organizations, as a $60 million, 5-year public–private partnership. The primary goal of ADNI has been to test whether serial MRI, PET, other biological markers, and clinical and neuropsychological assessment can be combined to measure the progression of MCI and early AD. Determination of sensitive and specific markers of very early AD progression is intended to aid researchers and clinicians to develop new treatments and monitor their effectiveness, as well as lessen the time and cost of clinical trials.

Subjects

The general eligibility criteria used for the inclusion of participants were those defined in the ADNI protocol (described in details at http://www.adni-info.org/Scientists/AboutADNI.aspx#). Enrolled subjects were between 55 and 90 (inclusive) years of age, had a study partner able to provide an independent evaluation of functioning, and spoke either English or Spanish. All subjects were willing and able to undergo all test procedures, including neuroimaging and agreed to longitudinal follow up. Between twenty and fifty percent must be willing to undergo two lumbar punctures, spaced one year apart. Specific psychoactive medications were excluded. General inclusion/exclusion criteria were as follows: healthy control subjects (HC) had Mini Mental State Examination (MMSE) scores between 24 and 30 (inclusive), a Clinical Dementia Rating (CDR) of zero. They were non- depressed, non MCI, and non-demented. MCI subjects had MMSE scores between 24 and 30 (inclusive), a memory complaint, had objective memory loss measured by education adjusted scores on Wechsler Memory Scale Logical Memory II, a CDR of 0.5, absence of significant levels of impairment in other cognitive domains, essentially preserved activities of daily living, and an absence of dementia. AD patients had MMSE scores between 20 and 26 (inclusive), CDR of 0.5 or 1.0, and met NINCDS/ADRDA criteria for probable AD. In this paper, we used a total of 500 subjects, including 180 AD patients, 172 MCI subjects and 148 HC individuals. The demographic characteristics of all subjects are shown in Table 1.

MRI acquisition

In this paper, we used T1-weighted MR images from 1.5 T scanners acquired according to the ADNI acquisition protocol (Jack et al., 2008). All MR images that we used had undergone specific preprocessing correction steps.

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