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Review

Automatic interpretation and writing report of the adult waking electroencephalogram ☆

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HIGHLIGHTS

- A computer-assisted system for automatic, systematic and comprehensive interpretation of the adult waking EEG was developed for the first time.
- This new system can provide a written report of the adult waking EEG which is in good conformity with the results of visual inspection of the same record by qualified electroencephalographers (EEGers).
- This system can be applied to the clinical diagnosis of EEG as a supplementary tool to the EEGer's visual inspection and to the education of EEG trainees and EEG technicians.

ABSTRACT

Automatic interpretation of the EEG has so far been faced with significant difficulties because of a large amount of spatial as well as temporal information contained in the EEG, continuous fluctuation of the background activity depending on changes in the subject's vigilance and attention level, the occurrence of paroxysmal activities such as spikes and spike-and-slow-waves, contamination of the EEG with a variety of artefacts and the use of different recording electrodes and montages. Therefore, previous attempts of automatic EEG interpretation have been focussed only on a specific EEG feature such as paroxysmal abnormalities, delta waves, sleep stages and artefact detection. As a result of a long-standing cooperation between clinical neurophysiologists and system engineers, we report for the first time on a comprehensive, computer-assisted, automatic interpretation of the adult waking EEG. This system analyses the background activity, intermittent abnormalities, artefacts and the level of vigilance and attention of the subject, and automatically presents its report in written form. Besides, it also detects paroxysmal abnormalities and evaluates the effects of intermittent photic stimulation and hyperventilation on the EEG. This system of automatic EEG interpretation was formed by adopting the strategy that the qualified EEGers employ for the systematic visual inspection. This system can be used as a supplementary tool for the EEGer's visual inspection, and for educating EEG trainees and EEG technicians.

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1. Introduction

Electroencephalogram (EEG) is conventionally interpreted by electroencephalographers (EEGers) through visual inspection. If EEG can be automatically interpreted, it is expected to be more quantitative and more objective than visual inspection, and evidence based as against experience based. However, in strong contrast to electrocardiogram (EKG) which can be automatically interpreted and has been universally applied for practical use in the clinical setting, the quantitative analysis of EEG which is necessary for its automatic interpretation is faced with great difficulties due to multiple reasons. First, EEG contains an astronomical amount of spatial as well as temporal information. Second, the background activity of EEG tends to fluctuate moment to moment depending on the subject's condition such as the vigilance and attention level. Third, EEG often contains various forms of paroxysmal abnormalities such as spikes and spike-and-slow-waves which have to be distinguished from the background activities as well as from various artefacts. Fourth, EEG is often contaminated with artefacts of biological source such as electromyogram (EMG), EKG, pulsation (plethysmogram), blinks, eye movements and sweating, and artefacts of technical origin, in particular electrode artefacts. Fifth, both bipolar and referential montages are commonly used so that the two montages can complement each other for providing the correct spatial information. These factors have made it difficult to practically apply the automatic interpretation system of EEG, if any, for clinical purposes (Anderson and Doolittle, 2010 for review). As a result, the previous attempts of automatic EEG interpretation have been focussed only on a specific EEG feature such as paroxysmal abnormalities, delta waves, sleep stages and artefact detection.

Automatic spike detection on either the scalp-recorded or depth-recorded EEG in epilepsy patients has been explored by a number of investigators (Gotman and Gloor, 1976; Gotman, 1982, 1985 for review; Frost, 1985 for review; Wilson et al., 1999; Wilson and Emerson, 2002 for review; van Putten, 2003; von Ellenrieder et al., 2012; Ayoubian et al., 2013). Automatic analyses of sleep stages by using EEG data have also been implemented by many investigators (Inoue et al., 1982; da Rosa and Paiva, 1993; Jobert et al., 1994; Strungaru and Popescu, 1998; Anderer et al., 2010; Jensen et al., 2010; Ronzhina et al., 2012; Brignol et al., 2013). The quantitative analysis of a specific EEG feature was applied to patients with ischaemic stroke mainly for obtaining its prognostic information (Nuwer et al., 1987; Nagata, 1989; Claassen et al., 2004; Finnigan et al., 2004, 2007; van Putten et al., 2004; van Putten and Tavy, 2004; Sheorajpanday et al., 2009, 2011; Cloostermans et al., 2011; Finnigan and van Putten, 2013 for review). Quantitative EEG analysis was also applied for the diagnostic aid of traumatic brain injury (Nuwer et al., 2005), psychiatric diseases (Leuchter et al., 2012), cognitive disorders (Melissant et al., 2005; Buscema et al., 2007; Rossini et al., 2008; Caso et al., 2012; Kim et al., 2012) and behavioural disorders (Mathewson et al., 2012).

When an experienced EEGer reads EEG, it appears as if he/she interprets each page of the record by just taking a quick look at it. However, its process actually involves a series of systematic analysis of spatial and temporal information about all frequency components that constitute the EEG, although the actual method employed by each EEGer might differ among EEGers to a considerable extent. Therefore, the present authors thought that it might be possible to establish a computer-assisted system for automatic interpretation of the whole EEG by adopting the strategy that the EEGers employ for the visual inspection.

To the authors' knowledge, a computer-assisted system for making automatic, systematic and comprehensive interpretation of the whole EEG and for writing the report has not been successfully achieved. In a majority of the previously reported studies, the target of automatic analysis was restricted to a specific EEG feature such as the posterior dominant rhythm (Nakamura et al., 1985; Marcuse et al., 2008; Lodder and van Putten, 2011) and the scalp topography of slow waves (Matsuoka et al., 1978). Recently, Lodder and van Putten (2013) attempted a quantitative analysis of the background activities of the adult waking EEG, and achieved the results which were in relatively good agreement with the consensus results of EEGers' visual inspection.

Since the early 1980s, the present authors, through close collaboration of clinical neurophysiologists with system engineers, have been engaged in the development of a computer-assisted system for automatic, systematic and comprehensive interpretation of the adult waking EEG and for writing its report (Nakamura et al., 1985, 1992, 1993, 1996; Bai et al., 2000a). The aim of the study was to automatically present a written report of EEG which was in good agreement with the report obtained by the EEGer's visual inspection. This article will review each process involved in the development of the present automatic EEG interpretation system in reference to previously reported studies related to the respective process.

2. Extraction of features of EEGer's visual inspection and quantitative scoring

The information about each frequency component, which is analysed by the systematic visual inspection of EEGers, is formed of (1) the posterior dominant rhythm: as to whether it exists or not, and its organisation and symmetry if it exists, peak frequency and its symmetry, amplitude and its symmetry, and the antero-posterior distribution; (2) beta rhythm: amplitude and its