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Research report

Brain functional connectivity patterns for emotional state classification in Parkinson's disease patients without dementia

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HIGHLIGHTS

- Recognize different emotional states using brain functional connectivity.
- EEG change is significantly different among emotional states of PD patients.
- Highest classification results for the proposed bispectral functional connectivity index.
- PD patients exists decline in cortical connectivity during emotion processing.

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ABSTRACT

Successful emotional communication is crucial for social interactions and social relationships. Parkinson's Disease (PD) patients have shown deficits in emotional recognition abilities although the research findings are inconclusive. This paper presents an investigation of six emotions (happiness, sadness, fear, anger, surprise, and disgust) of twenty non-demented (Mini-Mental State Examination score >24) PD patients and twenty Healthy Controls (HCs) using Electroencephalogram (EEG)-based Brain Functional Connectivity (BFC) patterns. The functional connectivity index feature in EEG signals is computed using three different methods: Correlation (COR), Coherence (COH), and Phase Synchronization Index (PSI). Further, a new functional connectivity index feature is proposed using bispectral analysis. The experimental results indicate that the BFC change is significantly different among emotional states of PD patients compared with HC. Also, the emotional connectivity pattern classified using Support Vector Machine (SVM) classifier yielded the highest accuracy for the new bispectral functional connectivity index. The PD patients showed emotional impairments as demonstrated by a poor classification performance. This finding suggests that decrease in the functional connectivity indices during emotional stimulation in PD, indicating functional disconnections between cortical areas.

1. Introduction

Parkinson's Disease (PD) is a progressive disorder which develops gradually and destroys the dopamine neurons in the substantia nigra pars compacta of the basal ganglia. The prime symptoms of the disease are tremor, muscular rigidity, bradykinesia, and postural instability. More studies are needed to understand the behavior by analyzing neural connectivities [1]. Studies have shown that subjects with PD have problems in deciphering emotions from speech [2,3] and facial expressions [4,5], display blunted startle eye-blink response to highly arousing unpleasant pictures [6,7] and blunted arousal ratings of highly arousing emotional pictures [8], although not all findings are consistent. A number of studies have not found any impaired performance on the recognition of facial emotions in their PD samples [9,10]. A few studies did not find any emotional deficits from prosody [11,12]. Altogether, research evidence from

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the literature supports the covenant on emotional impairment in patients with PD. Most of the aforementioned studies have relied on information from behavioral measures of PD patients (e.g., recognition tasks) and very few with physiological measures (e.g., startle eye-blink reflex) for emotion recognition.

In the past few decades, numerous studies have been conducted to recognize emotion in healthy controls (HC) based on their facial expressions, speech, body gestures, and biosignals from autonomous nervous system (ANS), such as Heart Rate Variability (HRV), Electrodermal Response (EDR) and Galvanic Skin Response (GSR) [13–16]. Signals from central nervous system (CNS), namely electroencephalogram (EEG), Magnetoencephalogram (MEG) [17], Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) are more reliable for emotion recognition than other modalities [18]. For instance, the muscle tension in the face gives rise to facial actions, or for circumstances of social masking (example, an angry person may smile) [19]. PD patients may be unable to express their emotion via face. Similarly, speech signals convey emotional information depending on the manner in which it is delivered by the participant. The biosignals from ANS and/or CNS are usually not purposely controlled by the person and can deliver true inherent emotional state [20]. The ANS signals like GSR are highly influenced by inspiration from physical activity and not emotion. EEG is non-invasive and provides better time resolution than other CNS signals. However, most existing research on emotional EEG has focused on single-electrode EEG characteristic responses rather than an array of EEG electrodes in HC participant [21–23]. For example, Baumgartner et al. showed that EEG activity over the left hemisphere increases in happy conditions compared to negative emotional conditions [22].

Mauss and Robinson reported that emotional state involves circuits rather than isolated brain regions [24]. Several neuroimaging methods like fMRI, PET etc., are used to analyse interconnected neuronal activities in several brain regions to detect the emotions in the brain [25]. The authors advance the idea that brain functional connectivity (BFC) index using EEG is an appropriate method to analyse emotional specificity in PD patients compared to HC participant. Different techniques/indices have been used in the literature to measure brain functional connectivity [17,26–28]. The most commonly used methods for analysing emotional EEG between each pair of electrodes are: correlation (COR), coherence (COH) [29,30] and phase synchronization index (PSI) [31,32]. Shin and Park used correlation coefficients to analyse the changes in emotional status in HC participants according to the surrounding temperature [33]. They reported that the correlation coefficient is larger at high room temperatures in the temporal and the occipital regions while viewing negative emotional stimuli. Hinrichs and Machleidt showed a different degree of coherence in the alpha band, particularly, larger coherence in happiness than in sadness [34]. Miskovic and Schmidt report viewing of high emotionally arousing images increases the coherence between the prefrontal and posterior association cortices than neutral images [35]. Costa et al. reported an overall increase of synchronization index between right and left frontal sites while viewing sadness compared with happiness emotion [36]. These studies support the hypothesis that BFC using EEG can differentiate between different emotional states and these connectivity indices may provide a new insight for understanding the brain regions connectivity during emotional information processing in PD.

Recently, chaos theory and nonlinear methods have been used to obtain hidden information related to properties such as similarity, predictability, reliability and sensitivity of the physiological signals [37–40]. EEG is a non-linear, non-stationary and non-Gaussian signal. Emotions are transient event and the momentary variations in the EEG signals can be evaluated by understanding the nonlinear behaviors present in signals. Higher order spectra (HOS) analysis is known to be an effective tool for the analysis of nonlinear systems [41]. This paper proposes a bispectrum-based phase synchronization index (bPSI) as a tool to extract the functional connectivity alterations in PD patients compared to control subjects during emotion processing. The objectives of this study are, (a) to reveal whether emotional states can be categorized through BFC indices by predicting six emotions in PD patients; and (b) to compare the performance of COR, COH, and PSI with bPSI for recognition of emotional states of patients with PD.

A description of the materials, including participant's details, emotion elicitation stimuli and data acquisition procedure used in this study is presented in the next section. Then, the research methodology is presented followed by results. Finally, the limitations and conclusion of the study are summarized in the last two sections.

2. Materials used

2.1. Ethical approval

Prior to the study formal approval from University Kebangsaan Malaysia (UKM) medical center, ethics committee for human research (Ref. number: UKM1.5.3.5/244/FF-354-2012) was obtained. All participants/caretakers provided written informed consent prior to the experiment. Each participant was paid 50 Malaysian Ringgit (US $15) as participation honorarium.

2.2. Participants

Twenty non-demented patients with PD (10 females and 10 males; all right-handed) and twenty healthy control subjects (11 females and 9 males; all right-handed) are involved in this research. The subjects suffering from PD were selected from UKM medical hospital in Kuala Lumpur, Malaysia. All PD participants diagnosed by neurologists were under the influence of medication during the

Table 1
Background and neurophysiological characteristics (mean ± SD) of participants with PD and healthy controls.

Variables	PD	HC	Statistical test	p-value*
Sample size, N	20	20	NA	NA
Age, yr	59.05 ± 5.64	58.10 ± 2.95	$t = 0.667$	$p = 0.509$
Female/male	10/10	11/9	$x^2 = 0.100$	$p = 0.752$
Formal education, yr	10.45 ± 4.86	11.05 ± 3.34	$t = -0.455$	$p = 0.652$
Mini-mental state examination score (range: 0–30)	26.90 ± 1.51	27.15 ± 1.63	$t = -0.502$	$p = 0.619$
Beck depression Inventory scale (range: 0–21)	5.80 ± 2.87	5.45 ± 2.18	$t = -0.433$	$p = 0.667$
Edinburg handedness inventory (range: 1–10)	9.55 ± 0.76	9.84 ± 0.72	$t = -0.818$	$p = 0.403$
Hoehn & Yahr (stage: 1/2/3)	2.25 ± 0.63	NA	NA	NA
Unified Parkinson's disease rating scale	17.05 ± 3.15	NA	NA	NA
Duration of disease, yr	5.75 ± 3.52	NA	NA	NA

Note: N, number of participants; SD, standard deviation; NA, not applicable.
* Significant at $p < 0.05$.