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Research report

The role of prefrontal cortex during postural control in Parkinsonian syndromes a functional near-infrared spectroscopy study

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ABSTRACT

Postural instability represents a main source of disability in Parkinsonian syndromes and its pathophysiology is poorly understood. Indirect probes (i.e., mental imagery) of brain involvement support the role of prefrontal cortex as a key cortical region for postural control in older adults with and without Parkinsonian syndromes. Using functional near infrared spectroscopy (fNIRs) as a direct online cortical probe, this study aimed to compare neural activation patterns in prefrontal cortex, postural stability, and their respective interactions, in (1) patients with Parkinsonian syndromes; (2) those with mild parkinsonian signs; (3) and healthy older adults. Among 269 non-demented older adults (76.41±6.70 years, 56% women), 26 individuals presented with Parkinsonian syndromes (Unified Parkinson's disease rating scale (UPDRS): 11.08±3.60), 117 had mild parkinsonian signs (UPDRS: 3.21±2.49), and 126 individuals were included as a healthy control group. Participants were asked to stand upright and count silently for ten seconds while changes in oxygenated hemoglobin levels over prefrontal cortex were measured using fNIRs. We simultaneously evaluated postural stability with center of pressure velocity data recorded on an instrumented walkway. Compared to healthy controls and patients with mild parkinsonian signs, patients with Parkinsonian syndromes demonstrated significantly higher prefrontal oxygenation levels to maintain postural stability. The pattern of brain activation and postural control of participants with mild parkinsonian signs were similar to that of normal controls. These findings highlight the online role of the prefrontal cortex in postural control in patients with Parkinsonian syndromes and afford the opportunity to improve therapeutic options for postural instability.

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1. Introduction

Postural instability represents a main limitation of older adults with Parkinson's disease (PD; Post et al., 2007; Muslimovic et al., 2008) as it contributes to falls (Kerr et al., 2010; Johnson et al., 2013), gait disorders (Chastan et al., 2009), disability (Muslimovic et al., 2008) and death (Auyeung et al., 2012; Cilia et al., 2014). Postural control mechanisms depend on sensory information received from the visual, proprioceptive, and vestibular systems as well as appropriate motor outputs. As postural conditions become more challenging (e.g., standing on a narrow support, unipedal stance, or even dual-tasking), regions including the prefrontal cortex (PFC; Mihara et al., 2008) and parietal lobes (Mihara et al., 2008; Huang and Hwang, 2013) become progressively more involved in its monitoring. An increase in cortical involvement has been demonstrated in normal aging (Zwergal et al., 2012; Sullivan et al., 2009), especially during challenging conditions (Goble et al., 2011). However, the conclusions of these studies demonstrating the cortical involvement on postural control have been limited by small sample sizes and do not include patients with Parkinsonian syndromes (PS). Studying the online neural correlates of postural control represents a technical challenge. Most previous studies examining postural control have employed indirect methods such as mental imagery of standing (Zwergal et al., 2012; Malouin et al., 2003; Jahn et al., 2004), virtual reality (Basso Moro et al., 2014; Ferrari et al., 2014) or even simulated active balance during supine position (Karim et al., 2014) instead of measuring activity online during actual standing. Findings from these studies employing indirect methods to assess cortical postural control suggest that the prefrontal cortex plays a critical role in healthy younger adults (Basso Moro et al., 2014; Ferrari et al., 2014) and in patients with neurological conditions like stroke (Fujimoto et al., 2014). However, in order to better understand the mechanism of postural instability in healthy older adults and in patients with PS, direct online cortical measurement in the prefrontal regions during upright standing is needed. Functional near-infrared spectroscopy (fNIRs) is a non-invasive neuroimaging technique that enables the direct measurement of cerebral activity in the prefrontal regions during standing, and helps circumvent the limitations of other neuroimaging methods to measure or assess prefrontal activity directly during task performance (Basso Moro et al., 2014; Fujimoto et al., 2014; Karim et al., 2013a).

The current study addressed the knowledge gap regarding online prefrontal neural correlates of postural control in PS. Studying PS patients not only has clinical relevance as it a common neurodegenerative condition in aging but also contrasting this disease group with individuals with normal aging and mild parkinsonian signs provides insights to aging effects on prefrontal postural control mechanisms. Oxygenated hemoglobin activation in the prefrontal areas was measured directly using fNIRs during upright standing in non-demented older adults. Specifically, we compared brain activation patterns in the PFC during postural performance, in patients with PS, to participants with mild parkinsonian signs (MPS) – transitional state between normal aging and Parkinsonian syndromes – and to healthy older participants without any MPS. Based on the role of the PFC in postural control in neurological conditions (Fujimoto et al., 2014; Mihara et al., 2012) and the neural inefficiency hypothesis which posits that greater brain activation is required to perform equal or worse behavioral performance (Holtzer et al., 2009), we hypothesize that patients with PS would demonstrate greater prefrontal activation and worse postural stability throughout the postural control task, compared to both healthy older adults and individuals with MPS.

2. Results

2.1. Demographics

A total of 269 non-demented adults age 65 and older were included in the current study (mean age: 76.41±6.70 years, 56% women). All participants were considered to be non-demented as determined by their AD8 scores (Galvin et al., 2005) and consensus diagnostic case conference (Holtzer et al., 2008). Additionally, participants were relatively healthy and cognitively intact as determined by their overall global health status score (GHS; 1.15±1.11) and overall cognitive functioning standard score on the Repeatable Battery for Assessment of Neuropsychological Status (RBANS; 92±12). All participants were categorized into one of three groups: MPS, PS, or healthy control (i.e., normal). As in our previous studies (Allali et al., 2014a; Mahoney et al., 2014), MPS were systematically ascertained in participants by the study clinician using the motor evaluation portion (Part III) of the original version of the Unified Parkinson's Disease Rating Scale (UPDRS; Fahn and Elton, 1987). MPS diagnosis was based on the presence of any one of the four cardinal features (bradykinesia, rigidity, rest tremor, or postural instability and gait disturbance, regardless of its severity (see Section 4 for specific details). For a diagnosis of PS, we applied the United Kingdom Parkinson's disease society brain bank clinical diagnostic criteria (Hughes et al., 1992) where presence of moderate to severe bradykinesia was required in addition to the presence of one additional cardinal feature. All other participants without presence of any cardinal features constituted the normal group. Of the 269 participants, 126 were considered normal, 117 presented with MPS, and 26 were diagnosed with PS.

Baseline characteristics of the sample are provided in Table 1 for each of the three diagnostic groups. Bradykinesia and rigidity were present in all PS patients, whereas PIGD was present in 50% and tremor in 15%. Within the MPS group, rigidity was the most common MPS domain (37%), followed by bradykinesia (23%), PIGD (19%), and tremor (6%). Participants in the control group were significantly younger than those in both the MPS and PS groups; as well, individuals in the MPS group were significantly younger than those in the PS group. Compared to healthy normal adults, those with MPS had significantly lower performance on the RBANS and those with PS endorsed significantly more symptoms of depression.

Oxygenated hemoglobin (HbO_2) data recorded from 16 fNIRs channels were used to characterize changes in