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Full Length Article

Cortical activation during balancing on a balance board

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ABSTRACT

Background: Keeping one's balance is a complex motor task which requires the integration and processing of different sensory information. For this, higher cortical processes are essential. However, in the past research dedicated to the brain's involvement in balance control has predominantly used virtual reality paradigms whilst little is known about cortical activation during the challenging balancing on unstable surfaces (e.g. balance board). Hence, the main goal of this study was the simultaneous evaluation of cortical activation patterns and sway parameters during balancing on a balance board.
Methods: Ten healthy adults were instructed to balance on a balance board while brain activation in supplementary motor area (SMA), precentral gyrus (PrG) and postcentral gyrus (PoG) was measured with functional near-infrared spectroscopy (fNIRS). Additionally, sway parameters were simultaneously recorded with one inertial sensor.
Results: Enhanced activation of SMA, PrG and PoG was observed when balancing was compared with still standing. Furthermore, the sway of pelvis (indicated by root mean square) increased in medio-lateral (ML) and anterior-posterior (AP) direction during the balance condition. Notably, a strong negative correlation was found between SMA activation and sway in ML direction during balancing, which was not observed during standing.
Conclusion: Our results underline the important role of sensorimotor cortical areas for balance control. Moreover, the observed correlations suggest a crucial involvement of SMA in online control of sway in ML direction. Further research is needed to understand the contribution of other cortical and subcortcial areas to online balance control.

1. Introduction

Maintaining and recovering of balance are complex processes which require the coordination of multiple joints and muscles. To do so, information from different sensory systems (e.g. vestibular, tactile, visual) has to be processed and integrated in order to perform motor adjustments. The vestibular system for example is important for the perception of self-motion and provides, in turn, vital sensory information for neuromotor control of postural balance (Brandt & Dieterich, 1999; Cullen, 2012; Day & Fitzpatrick, 2005; Dieterich & Brandt, 2015; Horak, 2010). Furthermore, the vestibular system has strong recip-

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rocal inhibitory connections with the visual system (Bense, Stephan, Yousry, Brandt, & Dieterich, 2001; Brandt, Bartenstein, Janek, & Dieterich, 1998; Brandt & Dieterich, 1999; Deutschlander et al., 2002) and presumably compensates for the decline of visual processing capabilities during aging (Faraldo-Garcia, Santos-Perez, Crujeiras-Casais, Labella-Caballero, & Soto-Varela, 2012). A widespread network of cortical structures (e.g. parieto-insular vestibular cortex (PIVC); superior temporal gyrus (STG); insular cortex) has been identified as crucial for the processing of vestibular and multisensory information in the brain (Dieterich & Brandt, 2008). These findings are based on functional magnetic resonance imaging (fMRI) studies using caloric (Fasold et al., 2002) or galvanic vestibular stimulation (Stephan et al., 2005). Similar results underlining the role of parieto-temporal areas in neuromotor control of postural balance, have been observed in studies employing fNIRS (Karim, Fuhrman, Sparto, Furman, & Huppert, 2013; Karim, Schmidt, Dart, Beluk, & Huppert, 2012; Takakura, Nishijo, Ishikawa, & Shojaku, 2015). fNIRS which measures the relative changes in hemoglobin concentration by means of near infrared light attenuation allows the quantification of cortical activity changes during the execution of movements (Leff et al., 2011). So far, fNIRS was used for studying cortical activity during walking (for review see Hamacher, Herold, Wiegel, Hamacher, & Schega, 2015), turning (Maidan et al., 2015) and balancing (Fujimoto et al., 2014; Karim et al., 2012, 2013; Mihara, Miyai, Hatakenaka, Kubota, & Sakoda, 2008; Takakura et al., 2015). However, most of this research has used either virtual reality paradigms (Basso Moro et al., 2014; Ferrari et al., 2014) or focused on neurological diseases (Fujimoto et al., 2014; Mahoney et al., 2015; Mihara et al., 2012). In contrast, balance training in therapeutic settings (e.g. rehabilitation) is usually conducted on unstable surfaces like foam pads or balance boards. Furthermore, prior fNIRS studies mainly evaluated the activation in prefrontal (Basso Moro et al., 2014; Ferrari et al., 2014; Mahoney et al., 2015; Mihara et al., 2008) or parieto-temporal brain areas (Karim et al., 2012, 2013). However, recent fMRI studies have provided evidence that motor areas like SMA and M1 play a considerable role in neuromotor balance control, too (Ferraye et al., 2014; Taube et al., 2015). This evidence is supported by a number of studies examining structural changes after training of a challenging whole-body balancing task (Taubert, Mehnert, Pleger, & Villringer, 2016; Taubert, Villringer, & Ragert, 2012; Taubert et al., 2010). Taken together, the contribution of sensorimotor areas during the execution of a demanding balance task on unstable surfaces has been poorly studied so far. As a consequence, our understanding of neuromotor balance control is still limited (Bolton, 2015). Therefore, the first goal of this exploratory study was to evaluate the effect of balancing on a balance board (also known as wobble board) on cortical activity in sensorimotor areas as assessed by fNIRS.

Furthermore, given the importance of higher cortical processes for postural balance control (Hülsdünker, Mierau, Neeb, Kleinöder, & Strüder, 2015; Jacobs & Horak, 2007) and the reported significant correlation of balance scores and brain activity in the SMA of stroke patients (Fujimoto et al., 2014; Mihara et al., 2012) we assumed a correlation between sway parameters and brain activity. Consequently, the second aim of this study was to identify possible relations between sway parameters and hemodynamic responses in sensorimotor brain areas.

2. Methods

2.1. Subjects

Ten healthy adults participated in the study (median age = 25 years, range 21–47 years; mean height = 1.77 ± 0.5 m; mean body weight = 76.10 ± 9.46 kg). No participant had a self-reported history of musculoskeletal diseases, balance problems or neurological impairments. Furthermore, all participants had normal or corrected vision. The participants had no prior experience in experimental and similar balance tasks and they did not practice special balance-requiring sports (e.g. gymnastics, slacklining). All participants were informed about the experimental procedures and gave written informed consent to participate. The study was approved by the local ethics committee and all procedures were conducted in accordance with the Declaration of Helsinki (1964).

2.2. Task procedures

Every participant performed three blocks altogether. A block consisted of three phases: at first participants had to stand still on the floor for 30 s (baseline) and then another 30 s for the standing condition. Afterwards, they were verbally asked to step on the balance board (TOGU® Balance Board Balllanza ® level 2; green, Prien-Bachham, Germany) and maintain balance there in feet side by side position for 30 s (balance condition). After each balancing period they had to step down and were allowed to rest standing on the floor for 30 s (see Fig. 1).

In order to minimize other possible confounding effects, participants were instructed to refrain from moving during the rest times, from speaking and from outstretching their arms during the experiment. Before the onset of the measurement a familiarization block involving the same experimental procedures was conducted. The measurements took place in a quiet room.

2.3. fNIRS measurement

A continuous fNIRS wave system (ETG 4000 Optical System; Hitachi Medical Corporation, Tokyo, Japan) that emits two different wave lengths (695 and 830 nm) was used in this study. The relative absorption changes of near-infrared light were