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Research article

# Standing still: Is there a role for the cortex?

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## HIGHLIGHTS

- Focused on cortical control of balance when standing still.
- Use of novel approach aligning EEG with naturally occurring postural sway reactions.
- Observed a naturally occurring instability-evoked N1 potential.
- Amplitude and spectral power increased with increased postural challenge.

## ARTICLE INFO

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## ABSTRACT

In humans, standing still appears so automatic that high-level cortical processes seem unnecessary. However, by measuring cortical activity time-locked to reactive control events arising from naturally occurring instability while standing still, we detected cortical involvement in the form of an evoked N1 potential prior to the onset of balance reactions. Peak amplitude and spectral power of this event-related activity increased as postural challenges and demand for reactive control increased.



## 1. Introduction

Humans take years to develop the ability to maintain static upright bipedal stance until it eventually becomes automatic. The apparent automaticity of balance control during upright stance led to a view that it may be largely reflexive, occurring at sub-cortical levels [1,2]. The support came originally from research on quadrupeds, where control of biomechanical demands, ontogenetic development, and habitual stance are very different [3]. However, bipedal stance is a remarkably complex task involving biomechanical and neuromotor challenges to position a high center of mass over a relatively small base of support through the control of a series of linked moveable segments [4]. The challenges to balance control become profoundly evident in the face of disorders such as Parkinson's disease, multiple sclerosis, stroke, peripheral neuropathy, and cerebellar ataxia [5]. Evidence from dual task paradigms, imaging, and electroencephalography (EEG) reveals a potential role for a cortical contribution into reactive balance control in response to externally or self-generated perturbations [6–9]. However, what is not clear is whether the cortex participates to control balance even when someone stands still.

Previous studies have used various imaging modalities like positron emission tomography (PET), transcranial magnetic stimulation (TMS), functional magnetic resonance imaging (fMRI), and EEG to study the cortical activations during unperturbed and imagined stance. PET imaging during standing with eyes open and closed has shown activation in the right visual cortex and prefrontal cortex, respectively [19]. Tandem stance with eyes open activated the visual association cortex [19]. TMS-evoked EMG responses were significantly increased while standing on a rocking platform as compared to standing on a rigid floor suggesting a potential role for the motor cortex in postural control [20]. fMRI during imagined stance has shown activations mainly in basal ganglia, cerebellar vermis and thalamus, but has also shown significant cortical activations in left superior frontal gyrus, left inferior frontal gyrus and

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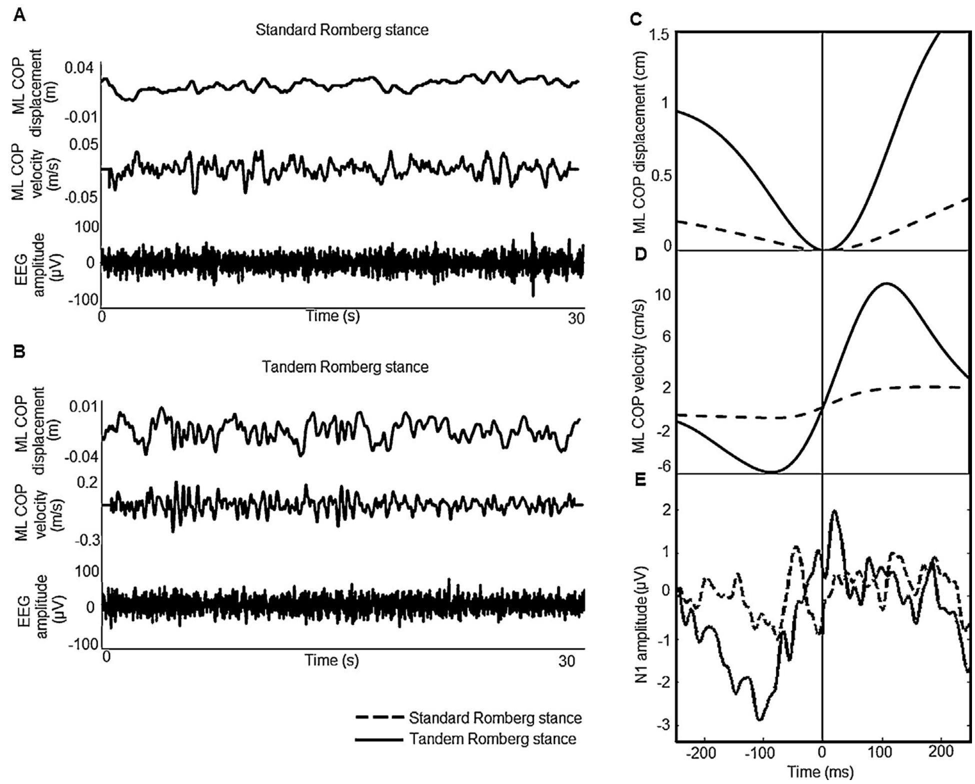


**Fig. 1.** ML COP excursions and naturally occurring instability-evoked N1. Single trial EEG, ML COP displacement, and ML COP velocity during 30 s of standard (A) and tandem (B) Romberg stances. Grand averaged ($n = 12$) ML COP displacement (C), ML COP velocity (D), and ERP at Cz electrode (E) in response to naturally occurring instability during standard (dashed line) and tandem (solid line) Romberg stances. $t = 0$ is the peak ML COP displacement which estimates the onset of corrective balance reactions to spontaneous postural sway.

bilateral medial temporal gyri [21]. More recently, EEG studies during standing with eyes open have reported event related desynchronization of alpha (8–12 Hz) rhythm and power increase in beta (13–19 Hz) and sigma (30–40 Hz) bands in the centro-parietal areas [22,23]. However, these studies considered stance as a continuous event and have not delineated the role of cortex in reactive balance control during stance.

The current study adopted a novel approach to reveal if the control of standing still involved the cerebral cortex. We assume that standing still is comprised of a series of discrete balance reactions to naturally-occurring time-varying instability and examined cortical activity associated with these reactions by time-locking EEG activity to transient center-of-pressure (COP) excursions that occur while standing still. To determine the dependence of cortical activation on the amplitude of these balance reactions, we evaluated the cortical activity associated with two tasks of varying postural challenges: standard and tandem Romberg stances.

## 2. Materials and methods

Twelve healthy volunteers (6 females and 6 males; age range 19–37 years) participated in this study. No subjects reported any history of neuromuscular disorders. Written informed consent was obtained from each participant, and the experimental procedures were performed in accordance with the declaration of Helsinki. The study was approved by the Research Ethics Board of the University of Waterloo.

The participants were instructed to maintain upright stance with equal weight on each foot while standing with eyes closed and arms crossed in two different postures: (1) Low balance challenge stance with two feet placed together (standard Romberg stance) and (2) high balance challenge stance with heel-to-toe (tandem Romberg stance). Romberg stances have been used in clinical balance assessment to examine the integrity of corrective postural control mechanisms [10]. The tasks, especially the standard Romberg stance, were easy for healthy young adults tested in this study. They did represent a modest increase in task challenge from standard stance position to tandem stance position which we exploited in the current study to ensure that we could more easily detect the discrete balance reaction events. Participants stood with each foot on a force plate. Prior to data collection, the participants rehearsed the two standing postures required to establish a standardized foot position on the force plates and the outline of the feet was traced in each stance to allow the same foot position to be maintained in all trials [11]. They were instructed to stand as still as possible in one of the stance position for 30 s with bare feet. For each participant, the order of the stance position was randomized and three trails were performed for each stance condition.

Spontaneous postural sway during standard and tandem Romberg stances were recorded using two force plates (AMTI OR6-5) that were positioned side by side underneath the subject's foot without touching (<1 mm apart). Ground reaction forces (Fx, Fy, and Fz) and moment components (Mx, My, and Mz) from the force plates were acquired and recorded using a custom-made program (LabVIEW, National Instruments, TX, USA). Force plate data were amplified (gain: 1000), low-pass filtered using two pole low-pass 1000 Hz filter (built in AMTI MSA-6 MiniAmp amplifier), sampled at a rate of 1000 Hz, and stored for subsequent analysis. To synchronize the posturography with electroencephalography (EEG), a triggering pulse was delivered to the EEG amplifier whenever the force plate starts collecting the data and the corresponding time point served as the starting point of 30 s stance.

EEG data were recorded continuously with Ag/AgCl electrodes mounted on a 32-channel electrode cap (Neuroscan, El Paso, TX, USA) based on the international 10–20 lead system. To monitor