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Review

Cortical activity during walking and balance tasks in older adults and in people with Parkinson's disease: A structured review

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ABSTRACT

An emerging body of literature has examined cortical activity during walking and balance tasks in older adults and in people with Parkinson's disease, specifically using functional near infrared spectroscopy (fNIRS) or electroencephalography (EEG). This review provides an overview of this developing area, and examines the disease-specific mechanisms underlying walking or balance deficits. Medline, PubMed, PsychInfo and Scopus databases were searched. Articles that described cortical activity during walking and balance tasks in older adults and in those with PD were screened by the reviewers. Thirty-seven full-text articles were included for review, following an initial yield of 566 studies. This review summarizes study findings, where increased cortical activity appears to be required for older adults and further for participants with PD to perform walking and balance tasks, but specific activation patterns vary with the demands of the particular task. Studies attributed cortical activation to compensatory mechanisms for underlying age- or PD-related deficits in automatic movement control. However, a lack of standardization within the reviewed studies was evident from the wide range of study protocols, instruments, regions of interest, outcomes and interpretation of outcomes that were reported. Unstandardized data collection, processing and reporting limited the clinical relevance and interpretation of study findings. Future work to standardize approaches to the measurement of cortical activity during walking and balance tasks in older adults and people with PD with fNIRS and EEG systems is needed, which will allow direct comparison of results and ensure robust data collection/reporting. Based on the reviewed articles we provide clinical and future research recommendations.

1. Introduction

Parkinson's disease (PD) causes walking and balance deficits [1,2] that lead to increased falls, reduced mobility and quality of life [3]. In general, 60% of older adults (> 80years old) have gait disorders [4] which cause 17% of falls [5], with higher incidences in PD [6]. While some gait impairments in PD, such as slow gait, may relate to primary pathophysiology (i.e. bradykinesia), others, such as increased gait variability may be compensatory in nature [7]. Animal model evidence denotes that voluntary movements are derived from motor commands projecting from the cortex to the brainstem and spinal cord [8,9–12]. Goal-directed behaviors, such as walking, are always accompanied by automatic processes of postural control involving balance adjustment and muscle tone regulation [8] that rely more on subcortical structures (i.e. basal ganglia and brain stem) [8]. PD impacts subcortical pathways leading to dysfunctional automatic movement control, which is suggested to be accompanied by a compensatory shift to more voluntary cortical control [10,13,14]. Therefore, walking may rely heavily on compensation from cortical structures in PD, which may also increase motor performance variability.

In parallel, other studies focus on the role of cognition in balance and gait dysfunction in PD [15]. Extensive associative behavioral studies have linked cognition to walking and balance performance [16,17], however these previous experiments have not investigated the neural mechanisms involved. Changes in brain structure and connectivity with ageing and PD impact cognitive processes, walking and balance [18,19], likely due to involvement of common neural centers. Specifically, white matter structural changes, lower hippocampal and anterior cortex volume relate to executive-attentional deficits with links to walking and balance impairment [15,20–22]. Therefore, disease-specific impairments of brain activity, motor control and cognition potentially mediate task performance. Examining underlying cortical

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activity involved in walking and balance in older adults and PD will allow further clarification of disease-specific links between these features.

Traditionally, brain structure and function have been studied using imaging techniques, such as functional magnetic resonance imaging [18,23,24]. The majority of studies have focused on investigation of motor regions (such as supplementary motor area (SMA), premotor (PMC), primary motor (M1) and sensorimotor cortices (SMC)) [25], with only a few recent studies examining the involvement of cognitive regions (such as prefrontal cortex (PFC)) [26–28]. Unfortunately, imaging results are limited as the head has to remain still and assays of walking and balance are used to mimic task performance (e.g. virtual reality or mental imagery), or studies use simple, single-segment motor tasks (e.g. finger tapping or button pressing) to infer cortical or subcortical activity related to general motor control.

Recent technological advances have allowed investigation of cortical activity during real-time walking or balance tasks in older adults and PD using functional near infra-red spectroscopy (fNIRS) or electroencephalography (EEG). However, this emerging body of literature has yet to be compiled for comprehensive methodological evaluation and interpretation. Greater understanding of cortical activity involved in walking and balance with age and PD will allow PD-specific cortical targets for intervention development to be uncovered. Therefore, we focused this review on the following: 1) cortical activity during real-time walking and balance tasks in older adult and PD subjects; 2) study protocols including cortical activity instrumentation and outcomes; and 3) clinical and future research recommendations.

2. Methods

2.1. Search strategy

Key search terms and synonyms are displayed within Fig. 1. All key terms were matched and exploded with medical subject headings (MeSH). Databases searched included Medline and PsychInfo, Scopus and PubMed (Fig. 2). Studies were deemed relevant if they incorporated terminology that focused on cortical activity during a walking or balance task in older adults or PD in the title, abstract or keywords. Initial title screen for relevant articles was performed by the reviewer (SS). Titles and abstracts were then further screened by three reviewers (SS; RV; RM). A final full-text review was performed if further clarity was required for articles meeting review criteria (Table 1).

2.2. Data extraction

Data was extracted and synthesized into tables by the reviewer (SS) and confirmed by the other reviewers (RV, RM, DM, PF) (Tables 2 and 3). Extracted data included first author and year of publication, population characteristics, cohorts, task, type of measurement device, regions of interest (ROI), signal pre-processing, outcome measures, key findings and interpretation.

3. Results

3.1. The evidence base

The initial search yielded 556 articles following duplicate exclusion (Fig. 2) [29]. Initial title and abstract screening resulted in 56 articles of interest of which 37 were identified for inclusion by three reviewers (SS, RV, RM), with consensus of article inclusions following consultation with the other adjudicating reviewers (DM, PF, MM). Reasons for exclusion of studies are included as Supplementary Material 1.

3.2. Participants

The reviewed articles (n = 37) investigated older adults and people with PD with an average age of 66.5 years and 78.2 years, respectively. Both male and female participants were recruited to the majority of studies, although several did not report gender characteristics (Table 2). Generally, PD participants were tested “ON” their parkinsonian medications, although some studies did not report medication status [30,31]. Fewer studies examined PD compared to older adult subjects.

Search string key terms

Older adult or neurodegenerative group: “Older adult” OR “healthy older” OR elderly OR “Parkinson*” (TITLE-ABS-KEY)

AND

Mobile imaging: eeg OR electroencephalography OR nirs OR fNIRS OR “functional near-infra*” OR “near-infrared spectroscopy” (TITLE-ABS-KEY)

AND

Brain Activity: “neural*” OR “neuronal*” OR “brain*” OR “motor*” OR “cogniti*” OR “cortical*” OR “subcortical*” OR “locomotor*” OR “executive*” (TITLE-ABS-KEY)

AND

Real-world task: gait OR walk OR walking OR “postural control” OR “balance control” OR “stand*” OR “locomot*” OR “ambulat*” OR “turn*” OR “mobil*” (TITLE-ABS-KEY)

NOT

monkey OR rat OR mouse OR mice (TITLE)

(*indicates a wildcard and ‘TITLE-ABS-KEY’ indicates a title, abstract and keyword search)

Fig 1. Search string used for study acquisition. This illustrates the four key terms used for this review and the synonyms used for each.