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Effects of aging on prefrontal brain activation during challenging walking conditions

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ABSTRACT

Background: Deficits in cognitive domains, in particular, those related to the prefrontal cortex, contribute to diminished walking performance in complex conditions in older age. Studies using functional near infra-red spectroscopy (fNIRS) reported inconsistent findings of brain activation age-related changes in response to increased task demands. We aimed to study the effects of aging on gait and prefrontal activation in complex walking tasks with internal and external task demands.
Methods: Twenty-three healthy young adults (30.9 ± 3.7 yrs) and 20 healthy older adults (69.7 ± 5.8 yrs) participated in this study. Gait and prefrontal activation were assessed during three walking conditions: (1) usual walking, (2) dual tasking (internal task demands) and, (3) obstacle negotiation (external task demands). fNIRS measured changes in oxygenated hemoglobin concentrations in the prefrontal cortex.
Results: Several gait measures were worse in older compared to younger adults under all walking conditions ($p < 0.005$). Even at the lowest level of challenge, older adults had significant increases in HbO2 levels during usual walking, relative to standing ($p = 0.006$). Both groups showed increased activation during dual-task ($p < 0.002$) and during obstacle negotiation ($p < 0.003$).
Conclusions: Prefrontal activation during walking is dependent on age and task properties and that older adults apparently rely more on cognitive resources even during usual walking task.

1. Introduction

Gait performance declines with older age and these changes have been associated with an increased risk of falls (Hausdorff, 2007; Mills & Barrett, 2001). Age-related gait changes are more pronounced when walking is combined with another cognitive concurrent task (i.e., dual-task) and during complex and challenging tasks such as obstacle negotiation(Beurskens & Bock, 2012b; Galna, Murphy, & Morris, 2010; Galna, Peters, Murphy, & Morris, 2009; Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010). Such tasks require executive function, attention, motor planning and processing of environmental stimuli, suggesting that cognition plays a role in mediating safe ambulation (Hausdorff et al., 2006; Herman et al., 2010; Montero-Odasso, Verghese, Beauchet, & Hausdorff, 2012; Beurskens & Bock, 2012b, 2012a; Mirelman et al., 2012). With aging, the reliance on cognitive resources increases to compensate for motor impairments (Cabeza, Anderson, Locantore, & McIntosh, 2002; Reuter-Lorenz, 2002; Steffener & Stern, 2012). In some cases, however, the challenge may exceed capacity and result in a motor failure such as a fall (Steffener & Stern, 2012).

In recent years, there is increasing interest in the use of functional Near Infra-Red Spectroscopy (fNIRS) to assess brain function and better understand motor-cognitive interactions. fNIRS is an optical imaging method based on hemodynamic responses as a surrogate measure of neural activation (Ferrari & Quaresima, 2012). In contrast to fMRI, fNIRS has the advantage of enabling exploration of neural activation during actual walking, in a natural setting, increasing the ecological validity of the measurements and findings. fNIRS has been used by

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several groups to explore the effects of aging on prefrontal cortex activation in response to increasing task demands such as dual tasking during walking (Holtzer et al., 2011, 2015). The findings are inconsistent. Holtzer et al. (2011, 2015) compared prefrontal cortex (PFC) activation during single and dual-task walking in younger and older adults. The dual-task condition was "walking while talking" (WWT) where locomotion was combined with verbal alphabet recall. They found higher prefrontal activation in dual compared to single-task walking, and this increase was slightly more pronounced in young than in older subjects. Ohsugi, Ohgi, Shigemori, and Schneider (2013) also found that both young adults and older adults showed increased PFC activation when a cognitive task was added to a stepping task. However, interestingly, they found that older adults had greater changes in neural activation compared to the young adults. In contrast, Beurskens, Helmich, Rein, and Bock (2014) compared performance in a visual complex dual task between older and young adults and reported that in the elderly, prefrontal activation was lower during dual-task walking with a complex visual task, compared to that of the young adults. Fraser, Dupuy, Pouliot, Lesage, and Bherer (2016) examined changes in cerebral oxygenation and cognitive accuracy during dual-task walking under different difficulty levels in younger and older adults walking on a treadmill. Difficulty effects were found in both the behavioral and fNIRS data but no significant age differences or age × condition interactions were observed. Previously, we reported that the properties of the "challenging" task resulted in different levels of frontal activation between tasks in older adults and patients with Parkinson's disease (Maidan et al., 2016), highlighting the importance of the specifics of the added challenge. Thus, these mixed findings may be related to differences in methodology i.e., over-ground walking vs. treadmill walking, specifics of the tasks, measurement tools, and subject samples. The lack of consensus warrants further investigation regarding the role of task properties and task difficulty in age-associated changes in prefrontal activation during walking.

To better understand the differences across studies, we investigated whether prefrontal activation differs in complex walking tasks with higher internal or external demands and how this is affected by the aging process. Dual tasking can be considered an internally driven process, while obstacle negotiation can be viewed as an externally driven process; each has been associated with distinct patterns of brain activation. For example, externally driven processes are associated with activation of caudal supplementary motor area and posterior occipital temporal areas, while internally driven processes involve activation of the rostral supplementary motor area and the adjacent cingulate cortex, as well as the PFC (Francois-Brosseau et al., 2009; Jenkins, Jahanshahi, Jueptner, Passingham, & Brooks, 2000). In addition, each task has been associated with different aspects of executive functions, i.e., obstacle negotiation with motor planning and visual spatial abilities while dual tasking with divided attention and working memory (Beurskens & Bock, 2012a; Beurskens et al., 2014; Galna et al., 2009; Herman et al., 2010). Both internally and externally driven tasks have been associated with PFC activation (Holtzer et al., 2011; Maidan, Nieuwhof, et al., 2016). We hypothesized that PFC activation will be larger among older adults during usual-walking, as compared to young adults, reflecting a greater reliance on cognitive compensation. In addition, we hypothesized that increased PFC activation will be dependent on the properties of the tasks, and more specifically, that there would be higher activation during internally driven tasks than during externally driven tasks. Finally, in older adults, we hypothesized that the changes in PFC activation would be associated with age-associated changes in gait.

2. Materials and methods

2.1. Participants

Twenty-three healthy young adults (mean 30.9 ± 3.7 yrs, 13 females) and 20 healthy older adults (mean 69.7 ± 5.8 yrs, 10 females) were included in this study. Participants were included if they were able to walk at least 5 min unassisted (e.g., no cane), and were cognitively intact based on the Montreal Cognitive Assessment score (Nasreddine et al., 2005) (> 26). Subjects were excluded if they had any underlying orthopedic or neurological disorders (e.g., stroke, traumatic brain injury), All participants provided informed written consent prior to participating in the assessment protocol. The study was ethically approved by the local human studies committee.

2.2. Protocol

Gait and PFC activation were assessed during three walking conditions: (1) walking at a self-selected comfortable speed (Usual Walking), (2) walking while serially subtracting 3 s from a 3 digit, predefined number (Dual-Task), and (3) walking while negotiating two physical obstacles (Obstacle), using a previously described protocol (Maidan, Nieuwhof, et al., 2016). Each condition started and ended with 20 s of standing quietly, with the instruction to refrain from talking and moving the head. After these 20 s, the instruction "start" was given. Participants walked back and forth in a 30 m walkway for thirty seconds five times. The quiet standing of 20 s before each task served as the baseline reference for HbO2 PFC perfusion, as described elsewhere (Maidan, Nieuwhof, et al., 2016; Mirelman et al., 2014). The order of conditions was fixed and similar for all participants. To minimize the effects of fatigue, participants were encouraged to rest between conditions.

2.3. Prefrontal lobe activation

As previously described (Maidan, Nieuwhof, et al., 2016; Mirelman et al., 2014), changes in oxygenated hemoglobin (HbO2) concentrations in the prefrontal cortex were measured with the PortaLite™ fNIRS system (Artinis Medical Systems, Elst, the Netherlands). The system uses near infrared light, which is transmitted at two wavelengths, 760 nm and 850 nm. Data was sampled with a frequency of 10 Hz. The PortaLite™ uses wireless technology (Bluetooth), allowing participants to walk without the restriction of wires. Two probes were placed on the right and left forehead of the participants, positioned based on the 10–20 EEG maps at a height of 15% of the distance from nasion to inion and at 7% of the head circumference to the left and right from midline, to avoid measuring the midline sinus. These locations roughly target left and right Brodmann's areas 10, the dorsolateral and anterior prefrontal cortex (PFC). The probes were attached to the skin using double-sided stickers and covered with a black cloth to prevent penetration of ambient light. Oxysoft version 3.0.52 (Artinis Medical Systems, Elst, the Netherlands) was used for data collection. Based on different absorption spectra, concentration changes of HbO2 in the targeted PFC were calculated from the changes in detected light intensity using the modified Lambert-Beer law, assuming constant scattering (Sakatani et al., 2006). The PortaLite™ has three transmitters and one receiver, with transmitter-receiver distances of 30, 35 and 40 mm.

2.4. Data processing

Pre-processing of the fNIRS signal was completed with custom-written MATLAB code (MATLAB Release 2015b, The MathWorks, Inc., Natick, Massachusetts) (Maidan, Nieuwhof, et al., 2016; Mirelman et al., 2014). The concentrations of HbO2 were exported for further data processing. A bandpass filter with frequencies of 0.01–0.14 Hz was used to reduce physiological noise such as heart beat and drift of the signal. To remove motion artifacts, a wavelet filter was used (Brigadoi et al., 2014; Cooper et al., 2012), followed by correlation based signal improvement (CBSI) (Brigadoi et al., 2014; Cooper et al., 2012; Cui, Bray, & Reiss, 2010). HbO2 concentration signals of the three channels of each probe were then averaged, resulting in an HbO2 signal for the