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ORIGINAL ARTICLE

Decreased automaticity contributes to dual task decrements in older compared to younger adults

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Abstract

Purpose To contrast older and younger adults' prefrontal cortex (PFC) neural activity (through changes in oxygenated hemoglobin) during single and dual tasks, and to compare decrements in task performance.

Methods Changes in oxygenated hemoglobin of dorsolateral PFC were monitored using functional near-infrared spectroscopy during single tasks of spelling backwards (cognitive task) and 30 m preferred paced walk; and a dual task combining both. Gait velocity was measured by a pressure sensitive mat.

Results Twenty sex-matched younger (27.6 ± 3.5 years) and 17 older adults (71.2 ± 4.9 years) were recruited. The left PFC oxygenated hemoglobin decreased from start (1st quintile) to the end (5th quintile) of the walking task in younger adults (−0.03 ± 0.03 to −0.72 ± 0.20 μM; $p < .05$) unlike the non-significant change in older adults (0.03 ± 0.06 to − 0.41 ± 0.32 μM, $p > .05$). Overall, oxygenation increased bilaterally during dual versus single walk task in older adults (Left PFC: 0.22 ± 0.16 vs. −0.23 ± 0.21 μM, respectively; Right PFC: 0.17 ± 0.18 vs. −0.33 ± 0.22 μM, respectively), but only in right PFC in younger adults (−0.02 ± 0.15 vs. − 0.47 ± 0.13 μM). Older adults exhibited lower velocity during the dual task compared to younger adults (1.03 ± 0.16 vs. 1.20 ± 0.17 m/s, respectively). Older age was associated with dual task cost on velocity during walking after adjusting for confounding variables.

Conclusions Age-related cognitive decline in older adults may increase neural activity for cognitive tasks and diminish walking automaticity that may lead to decrements during dual tasking; the greater PFC increases in the oxygenated hemoglobin and lower velocity may be due to increased cognitive load and limited attentional resources.

Keywords Automaticity · Gait · Prefrontal cortex · Near-infrared spectroscopy · Frailty

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Abbreviations

ΔO_2Hb	Changes in oxygenated hemoglobin
BMI	Body mass index
fNIRS	Functional near-infrared spectroscopy

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PFC	Prefrontal cortex
PPW	Preferred paced walk
Q1	First quintile
Q5	Fifth quintile
SB	Spelling backwards

Introduction

In healthy adults, routine tasks such as walking are automatized. Movement automaticity refers to the ability of central nervous system to enable walking with minimal use of cognitive resources (e.g., attention) (Clark 2015). Healthy older people walk more slowly, with a shorter step length and greater stance width; all of these gait changes appear to be directed towards improving walking stability and may indicate a loss of automaticity (Guimaraes and Isaacs 1980). Consequently, the inability of maintaining task automatization is postulated to contribute to dual task decrements, poor balance and even falls (Silsupadol et al. 2009). A decline in automaticity in older adults may be improved by dual task training that has shown to improve balance and cognitive measures (Silsupadol et al. 2009); however, literature on the associated mechanisms is lacking.

The prefrontal cortex (PFC) is responsible for executive functions involved in walking and cognitively challenging tasks (Nóbrega-Sousa et al. 2020). These cognitive functions decline with age, leading to cognitive impairment and increased fall risk (Herman et al. 2010). Difficult tasks involving high attentional demands, working memory and motor planning can result in loss of automaticity and lead to increased activation of PFC (MacDonald et al. 2000; Holtzer et al. 2014; Salzman et al. 2021). In contrast, a decrease in PFC activity at the end of the task, relative to the beginning would suggest automaticity (Clark 2015; Stuart et al. 2019). A greater decrease suggests a greater level of automaticity (Vandenbossche et al. 2013; Hermand et al. 2020). However, age-related cognitive decline may negate these changes and alternatively be counterbalanced by neural mechanisms such as compensation (Cabeza et al. 2018).

Compensation refers to the increased recruitment and interaction between PFC and other brain regions when a particular neural region has declined performance as a result of aging or a neurological condition. This increased activity in the brain is postulated to improve performance of the task at hand. Compensation has been documented in older compared to younger adults during tasks with relatively low cognitive demand (e.g., memorization), a marker of cognitive frailty (Cabeza et al. 2002). Cognitive frailty as manifested by cognitive impairment and physical frailty (Bu et al. 2021) can be accentuated during dual tasking resulting in decrement in performance of one or both tasks (cognitive and/or motor). This is termed dual task cost. Decrements commonly occur when attentional demand of performing two tasks concurrently exceeds an individual's attentional capacity, which increase with age and is a sign of cognitive frailty (Al-Yahya et al. 2011). The capacity sharing model explains this phenomenon of limited attentional capacity and suggests that pools of processing resources are divided when multitasking. When one task is prioritized during dual tasking, more cognitive resources are allocated towards it, which may result in a decline of performance in the second task (Tombu and Jolicoeur, 2003). Therefore, automaticity of a task that is not prioritized during dual task performance may decline if attentional resources are not directed towards it.

The neurovascular coupling associated with cognitive and motor tasks can be evaluated using functional near-infrared spectroscopy (fNIRS) that measures relative changes in oxygenated hemoglobin (ΔO_2Hb) to infer neuronal activity (Holtzer et al. 2014; Maidan et al. 2016; Hawkins et al. 2018). fNIRS has several distinct qualities that are advantageous to provide a measure of neural activity by quantifying ΔO_2Hb (Piper et al. 2014). A more conventional neuroimaging method is functional magnetic resonance imaging (fMRI) that indirectly measures neuronal activity using blood-oxygen-level dependent (BOLD) imaging. However, fMRI cannot be used to monitor neuronal activity during physical movements required for daily activities such as walking. Further, access is limited, it is expensive and it is limited by claustrophobia in some participants. In contrast, fNIRS provides real-time measurements, allows measurement during movement, is relatively unobtrusive and is inexpensive (Clark 2015). Examining dual task cost while monitoring dorsolateral PFC ΔO_2Hb may provide insights into the cognitive load of single versus dual task as well as whether automaticity occurs during walking in younger and older adults (Clark 2015; Stuart et al. 2019; St-Amant et al. 2020; Salzman et al. 2021).

Previous studies have analyzed the PFC ΔO_2Hb in younger adults (Techayusukcharoen et al. 2019), and older adults (Harada et al. 2009; Chen et al. 2017; Corp et al. 2018; Ross et al. 2021), during a cognitive task and/or walking. Dual tasking involving usual paced walking has shown to increase PFC O_2Hb in both older and younger adults (Holtzer et al. 2011, 2015; Fraser et al. 2016) and worsen gait performance especially in older adults, but the findings of mental tracking tasks as they relate to gait that involve manipulating information in the working memory are inconsistent (Al-Yahya et al. 2011; Pelicioni et al. 2019). Moreover, studies have also shown mixed results regarding which of the two groups has greater PFC ΔO2Hb during dual tasking. Holtzer et al. (2011) reported greater increase in younger adults, while Beurskens et al. (2014) reported a decrease in older adults. In contrast, higher PFC ΔO2Hb has also been reported in older compared to younger adults (Fraser et al. 2016; Mirelman et al. 2017). To date, evaluation of both left and right dorsolateral PFC ΔO_2Hb to assess automaticity comparing younger and older adults during walking in dual task studies has not been reported. Comparison of left and right dorsolateral PFC ΔO_2Hb is important to elucidate the impact of aging on unilateral versus bilateral activity differences in younger and older adults.

In order to elucidate neural correlates of walking performance and its automaticity, the objectives of this study were to (1) compare dorsolateral PFC ΔO_2Hb and changes in cognitive and gait performance between single and dual tasks within and between healthy younger and older adults; (2) compare PFC ΔO_2Hb at the beginning and end of the tasks to assess automaticity; (3) determine the contribution of age to dorsolateral PFC ΔO_2Hb, and dual task cost on velocity and spelling backwards accuracy while controlling for potential confounders.

Materials and methods

Participants

Healthy younger ($n=20$) and older participants ($n=17$) were recruited through emails and flyers from the University of Toronto, University Health Network associated hospitals and community centers in downtown Toronto, Canada. The sample size calculation based on 80% power to detect a standardized effect size of 0.80 at $p<0.05$ required 20 participants per group for between group differences and 11–12 for within group differences. Inclusion criteria were healthy men and women aged between 18 and 35 years (younger group) and ≥ 65 years (older group). Exclusion criteria were: current smokers; acute illness within 3 months; unstable cardiovascular, neurological or musculoskeletal conditions that interfere with independent ambulation or ability to stand on one leg; and cognitive impairment or lack of English fluency that may interfere with providing informed consent or following study instructions. All participants provided written informed consent before participation. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Research Ethics Board of University of Toronto (protocol ID: 33,466).

Procedure

In this cross-sectional study, participants' safety during exercise was screened with the American College of Sports Medicine questionnaire (Thompson et al. 2010). Anthropometric measures (height and weight) and hand and leg dominance were recorded. Questionnaires were then administered: (1) *Digit Span Forward and Backward Tests* (Wechsler 1997) were administered up to 5 digit sequences. Participants recalled 2–5 digit sequences in the same or reverse-order until two sequences with the same number of digits could not be recalled (Wechsler 1997); (2) *Montreal Cognitive Assessment* (MoCA) a valid and reliable screening tool for cognitive dysfunction (Nasreddine et al. 2005) evaluated attention and concentration, executive functions, memory, language, visuo-constructional skills, conceptual thinking, calculations, and orientation; (3) *Medication and Comorbidities Questionnaire* was used to document participants' medications and health conditions (Deyo et al. 1992); (4) *Single Leg Stance,* a balance test, asked participants to stand on their dominant leg for as long as they could, while bending the non-dominant leg at 90° angle with hands on hips (Friden et al. 1989). The BIOPAC wireless fNIRS device model FNIR100W-1 (fNIR Devices LLC, Potomac, MD) was secured over the participants' forehead (McKendrick et al. 2017) to record dorsolateral PFC ΔO_2Hb during all subsequent measures. Before and after each single and dual task, the participants completed a baseline task that involved spelling words forward from flashcards for 1 min. Two single tasks were performed in random order: (1) preferred paced walk; and (2) spelling backwards as the cognitive task. Subsequently, a dual task was performed, which paired tasks 1 and 2.

A BIOPAC wireless fNIRS device with 2 emitters and 4 detectors was secured over the forehead; the emitters were vertically aligned with the participants' iris (Fig. 1). Light

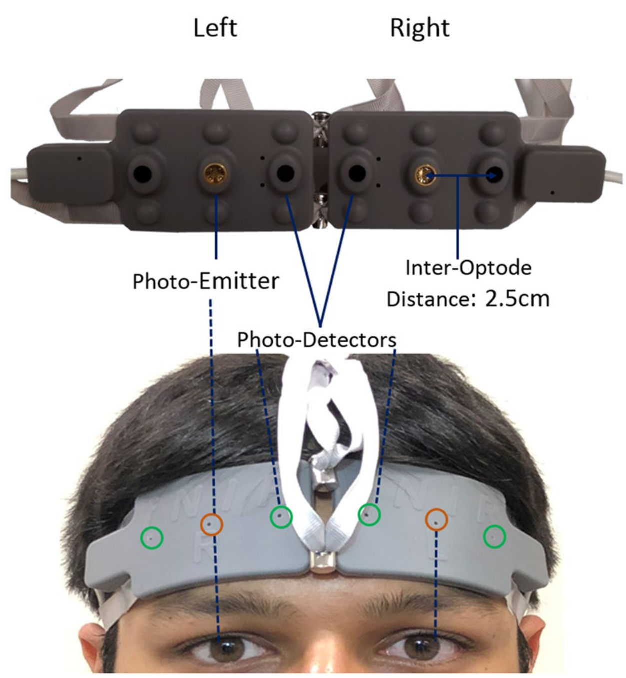

Fig. 1 fNIRS device (posterior aspect) showing 2 emitters and 4 detectors on its inner surface (upper image). The device was positioned over the forehead (lower image) and the emitters were aligned vertically with the iris (Ayaz 2010). The interoptode distance between the emitters and the detectors was 2.5 cm

intensity data at 730 nm and 850 nm were obtained using Cognitive Optical Brain Imaging (COBI) Studio at a frequency of 4 Hz and processed in fnirSoft (Drexel University, Philadelphia, PA) (Ayaz 2010). LED current and detector gain settings were adjusted to prevent low or saturated light signals for each participant. A low-pass, finite impulse response, filter with hamming order 57 and cutoff frequency of 0.05 was applied to attenuate physiological artifacts of respiration and pulse. Data were inspected for motion artifacts visually and through the Sliding Motion Artifact Rejection algorithm. ΔO_2Hb were calculated using the modified Beer-Lambert law (Artinis Medical Systems 2000).

Single and dual tasks

Participants performed two single tasks in random order and then in combination as a dual task: (1) Spelling Backwards, is classified as a mental tracking task. Participants were asked to spell 5 letter words backwards (Hollman et al. 2010) that were read out loud by the investigator from a list of 100 unique words for 1 min. Spelling accuracy and number of words attempted were recorded. This task was considered relevant to daily activities that require multitasking, and holding information in mind while performing a mental task (i.e., making purchasing decisions while shopping). (2) Walking Tasks (Bonetti et al. 2019) involved preferred (usual pace) paced walking for 30 m (6 passes) over a 5×0.88 m pressure sensitive Zeno Walkway (ProtoKinetics LLC, Havertown, PA) that contained a grid of 13,824 sensors. Gait velocity was calculated using the ProtoKinetics Movement Analysis Software (ProtoKinetics LLC, Havertown, PA). Preferred paced walking task was chosen to mimic the more usual pace of walking during activities of daily living.

Statistical analysis

Two-way mixed analysis of variance (ANOVA) tested differences in mean ΔO_2Hb data of entire tasks' duration between tasks and groups for: (1) left and (2) right PFC. Post hoc tests used *t* tests. One-way repeated measures ANOVA compared ΔO_2Hb during both walking tasks between left and right PFC in each group with Bonferroni post hoc test. Paired sample *t* tests compared velocity between tasks, within each group, and Wilcoxon signed rank test for ordinal data (words spelled backwards) (Manor et al. 2016). Decrements of spelling backwards accuracy and gait velocity were calculated as follows:

$$\text{Dual task cost} = \frac{\text{dual task} - \text{single task}}{\text{single task}} \times 100\%.$$

Using two-way mixed ANOVA, automaticity of walking was assessed by examining the PFC ΔO_2Hb during the first quintile (Q1) compared to the fifth quintile (Q5) of walk duration and contrasted between groups. Although not hypothesized to decrease, a similar analysis (two-way mixed ANOVA) examined differences of spelling backwards PFC ΔO_2Hb between time points (Q1 vs Q5) and groups. Differences in participant group characteristics were compared using unpaired *t* tests and proportions were tested using Chi-squared (i.e., sex, handedness). Multiple linear regression was used to determine the contribution of age to outcome variables—dorsolateral PFC ΔO_2Hb and dual task cost on spelling backwards accuracy and gait velocity—while adjusting for confounding variables: Montreal Cognitive Assessment scores and single leg stance duration. Statistical tests were performed in SPSS (version 27).

Results

Participants' characteristics

The older group was similar to the younger group in several attributes but differed in age (mean 27.6 versus 71.2 years), had a 13% higher BMI, had more comorbidities, took more medications and had a single leg stance duration that was 26.3% of the duration shown by younger adults (Table 1). Within the younger adults group, 11/20 (55%) participants had a normal BMI (18.5–24.9 kg/m^2), 6/20 (30%) were overweight (25.0–29.9 kg/m^2), while 1 (5%) was underweight (< 18.5 kg/m^2) and 2 (10%) were obese (> 30.0 kg/m^2). On the other hand, 5 (29.4%), 5 (29.4%) and 7 (41.2%) of 17 older participants were of normal weight, overweight and obese according to BMI cut-offs guidelines (WHO, 2020). Using MoCA cut-off score of < 26 (Nasreddine et al. 2005), 16/20 participants in the younger and 10/17 in the older adults group were above the threshold for not having cognitive impairment.

PFC neural activity—O_2Hb

In older adults, O_2Hb increased bilaterally ($p < 0.050$) during the preferred paced walking dual versus single task (left PFC: t(16), 1.87, $p = 0.040$, d = 0.45; right PFC: t(16) = 2.39, $p = 0.015$, d = 0.58) (Fig. 2); in contrast, O_2Hb only increased during preferred paced walk dual compared to single task in the right PFC (t(19) = 2.36, $p = 0.015$, d = 0.53) in younger adults. No significant interactions were found between groups and two walking tasks for ΔO_2Hb using mixed ANOVA. Moreover, no significant differences were found between any of the four tasks in left or right PFC ($p > 0.050$).

The increase in left and right PFC O_2Hb during spelling backwards from Q1 to Q5 tended to be higher in

Table 1 Characteristics of participants

	Younger ($n = 20$)	Older ($n = 17$)	P†
Sex (n of M:F)	10 M:10F	9 M:8F	0.858
Age (years)	27.6 ± 3.5	71.2 ± 4.9	**< 0.001**
Height (m)	1.7 ± 0.1	1.6 ± 0.1	0.146
Weight (kg)	69.3 ± 15.8	73.1 ± 15.1	0.455
BMI (kg/m^2)	24.1 ± 3.8	27.2 ± 4.6	**0.036**
Handedness (n)	20R	15R, 2L	0.115
Dominant Leg (n)	12R, 8L	7R, 10L	0.254
Digit Span Forward n (%)*	20 (100)	20 (100)	–
Digit Span Backward n (%)*	11 (55.0)	10 (58.8)	0.493
Montreal cognitive assessment (MoCA)	27.4 ± 2.4	25.6 ± 2.9	0.055
Comorbidities (range)	0.5 ± 1.0 (0–4)	2.3 ± 2.7 (0–10)	**0.014**
Medications (range)	0.3 ± 0.8 (0–3)	1.5 ± 1.6 (0–5)	**0.013**
Single leg stance duration (s)	109.1 ± 89.9	28.7 ± 29.1	**0.001**

Mean ± SD reported unless stated otherwis

BMI body mass index, *F* female, *L* left, *M* male, *R* right, *s* seconds, *n* number of participants

*number of participants that correctly recalled five digit sequence(s)

†p values for comparisons between groups

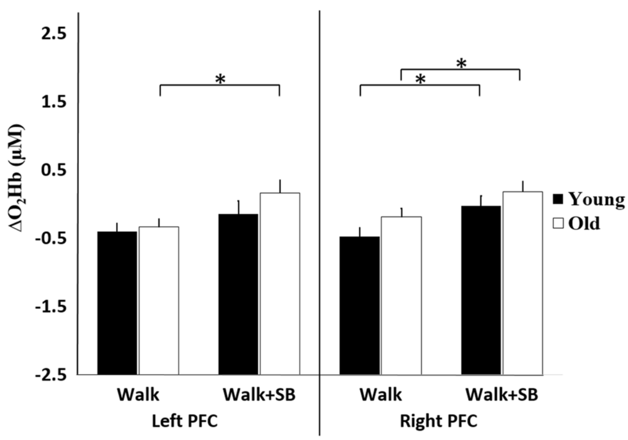

Fig. 2 Dorsolateral prefrontal cortex changes in oxygenated hemoglobin (PFC ΔO_2Hb) during single and dual tasks (mean ± standard error). In older adults, O_2Hb increased during preferred paced walk dual (PPW + SB) versus single task (PPW) in the left and right PFC, but only in the left PFC in younger adults. *indicates differences at $p < .05$

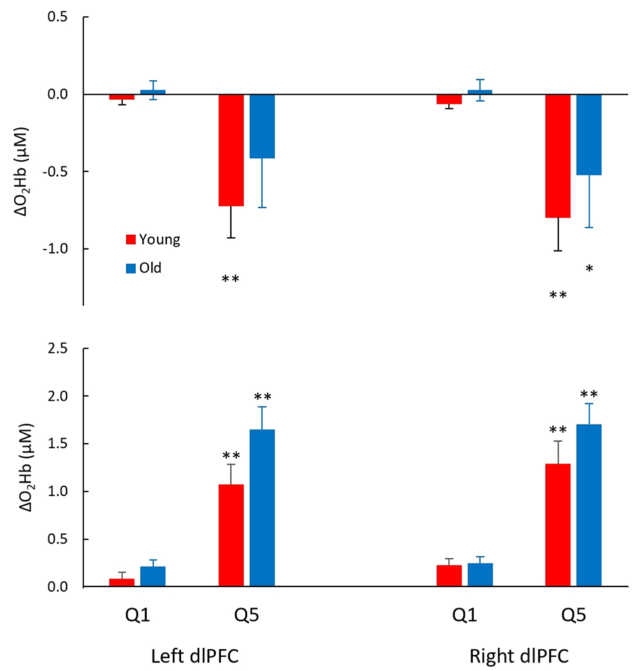

Fig. 3 Changes in left and right dorsolateral prefrontal cortex (dlPFC) ΔO_2Hb during the first (Q1) and last quintile (Q5) of the single tasks: preferred paced walking (upper panel) and spelling backwards (lower panel). Means and standard errors are shown. *Fifth quintile different than first quintile at $p = 0.035$; **difference at $p \leq 0.002$.Decreased automaticity contributes to dual task decrements in older compared to younger adults

older compared to younger adults (left PFC: $t(35) = 1.68$, $p = 0.051$, $d = 0.555$; right PFC: $t(35) = 1.50$, $p = 0.072$, $d = 0.494$, respectively). Both groups increased in left and right PFC O_2Hb during spelling backwards from Q1 to Q5 ($p \leq 0.003$) (Fig. 3). During preferred paced walk, older adults only showed a significant decrease in right PFC O_2Hb ($t(16) = 1.939$, $p = 0.035$, $d = 0.470$) whereas younger adults showed significant decreases in PFC O_2Hb bilaterally from Q1 to Q5 (left PFC: $t(18) = 3.422$, $p < 0.002$, $d = 0.785$; right PFC: $t(19) = 3.471$, $p < 0.002$, $d = 0.776$, respectively) (Fig. 3).

Dual task cost on gait velocity and cognitive task accuracy

Although both groups had a similar single task preferred paced walk velocity, dual task velocity in young adults did not change. In contrast, dual task velocity in older adults decreased compared to single preferred paced walk task ($p < 0.003$), which was significantly lower than the younger groups' dual task velocity ($p = 0.002$). Moreover, older adults showed a greater dual task decrement compared to the younger group ($p = 0.001$).

Older adults compared to younger adults spelled fewer words during the single spelling backwards task ($p = 0.039$) and were less accurate ($p = 0.049$) (Table 2). Both groups attempted fewer words during the dual task compared to single spelling backwards task ($p < 0.003$) (Table 2). Compared to the single spelling backwards task, the younger adults had reduced accuracy during the dual task unlike older adults (Table 2).

Effect of age on outcome variables

Linear regression indicated that older age was significantly associated with dual task cost on velocity during preferred paced walking ($F(3,33) = 5.87$, $p = 0.002$, adjusted $R^2 = 0.289$) after adjusting for single leg stance duration and Montreal Cognitive Assessment scores (Table 3). Age explained 29% of the variation in preferred paced walk velocity ($R^2 = 0.29$). Age was not significantly associated with the right or left dorsolateral PFC ΔO_2Hb or dual task cost on spelling backwards accuracy during the dual task.

Adjusted $R^2 = 0.29$, SE of the estimate = 10.88, effect size = 0.41, power = 0.88

Discussion

Comparison of results to literature

The aging-related neurophysiological changes associated with the interaction of cognitive impairment and physical frailty (e.g., diminished walking automaticity) are not well understood. The unique findings of this study were that the overall O_2Hb increased bilaterally in the dorsal PFC during preferred paced walking dual versus single task in older adults, but only in the right PFC in younger adults. In contrast, the younger group showed signs of automaticity bilaterally in the PFC during single task walking and lower increases during the single task backwards spelling. As expected, both groups did not show signs of automaticity during the spelling backwards task. The combined absolute higher levels of O_2Hb in older adults during spelling backwards and walking, may have contributed to the unilateral decrease in PFC O_2Hb during walking unlike the

Table 3 Regression model of the association of age to dual task cost on velocity after adjusting for covariates

Predictor variables	Unstandardized coefficients		Standardized coefficients	*t*	*p*
	B	SE B	β		
Model 1: Association of age to dual task cost on velocity during preferred paced walk and spelling backwards after adjusting for Montreal Cognitive Assessment (MoCA) scores and single leg stance (SLS) duration					
Age	−0.383	0.096	−0.664	−3.986	< 0.001
MoCA score	0.077	0.737	0.016	0.104	0.918
SLS duration	−0.041	0.027	−252	−1.532	0.135

Table 2 Spelling backwards (SB) accuracy and gait velocity of younger and older adults

Single and dual task	Outcome	Younger ($n = 20$)	Older ($n = 17$)	*p*†
Spelling backwards (SB)	SB accuracy (%) words attempted (*n*)	94.1 ± 8.5 11.3 ± 3.5	85.5 ± 18.8 9.3 ± 1.9	0.049 0.039
PPW + SB	SB accuracy (%) words attempted (*n*) dual task cost (%)	85.0 ± 20.3* 7.0 ± 2.4** −10.5 ± 18.4	81.0 ± 25.9 6.8 ± 1.5** −7.4 ± 29.9	0.611 0.791 0.720
PPW	Velocity (m/s)	1.21 ± 0.16	1.21 ± 0.14	0.898
PPW + SB	Velocity (m/s) dual task cost (%)	1.20 ± 0.17 −0.8 ± 10.6	1.03 ± 0.16** −14.5 ± 11.6	0.002 0.001

Mean ± SD are reported

m/min meters per minute, *PPW* preferred paced walk, *SD* standard deviation

**Single task different than dual task at $p < 0.003$; *single task different than dual task at $p < 0.033$

†*p* values for between groups comparisons

bilateral decrease in the younger group. Of clinical importance, walking velocity decreased during dual compared to single task in older adults in contrast to younger adults. The impact of age on velocity was confirmed using regression analysis adjusted for MoCA scores (assessment of cognitive impairment) and single leg stance duration (assessment of balance).

Higher ΔO_2Hb bilaterally during dual versus single tasking in older, in contrast to younger adults, may be explained by hemispheric asymmetry reduction in older adults (HAROLD) model, which attributes bilateral activity to declining unilateral neural efficiency and an inability to recruit required neural regions (Li et al. 2009). The increased PFC neural activity during dual tasking may result from less efficient neural processing (Cabeza et al. 2018; Li et al. 2018) and greater cognitive demands (i.e., compensation) for intentional movement control and goal oriented preparation for upcoming sequential gait steps in older adults (Pochon et al. 2001; Harada et al. 2009). In particular, the increases in left PFC O_2Hb during dual tasking in older adults may be reflective of divided attention and the need for language processing, whereas increases in the right PFC may be indicative of sustained attention and episodic memory retrieval (Cabeza and Nyberg 2000). Mental tracking tasks that involve manipulating information in working memory (e.g., backwards spelling) are linked to bilateral PFC activation (Petrides 1995). These higher PFC demands are consistent with early signs of cognitive impairment in older adults.

Time series analysis of PFC ΔO_2Hb was used to evaluate automaticity (Vandenbossche et al. 2013; Hawkins et al. 2018; Hermand et al. 2020). Backwards spelling is a cognitively challenging task containing all unique words, thus making it very difficult to become automatized. Thus, as expected, both young and old adults failed to show automaticity and exhibited higher PFC ΔO_2Hb at the end relative to beginning of the task. On the other hand, automaticity was more apparent during walking. Moreover, bilateral versus unilateral evidence and larger effect sizes were observed in younger compared to older adults during walking. Similar walking velocity was observed during this routine task in both groups but the greater dual task cost in older adults is consistent with a decline in automaticity and calls for attention to cognitive-motor rehabilitation interventions to restore walking automaticity.

The dual task cost on velocity during preferred paced walking was found to be dependent on age. This is corroborated by a meta-analysis on dual tasking (Al-Yahya et al. 2011). In the present study, age explained 29% of the variance in dual task cost during preferred paced walking. The decrements observed during dual tasks might be due to higher attentional and executive functions demands for maintaining dynamic balance during gait, (Patel et al. 2014) as executive functions and the associated neural networks walking and spelling backwards may be intertwined (Smith et al. 2016). Therefore, diversion of limited and diminished cognitive resources from more demanding task of maintaining balance during the dual task may explain the reduction in velocity in the older group and their increased risk of falls during activities of daily living.

Decrements in velocity and spelling backwards accuracy may be explained by capacity sharing model (Tombu and Jolicoeur, 2003; Patel et al. 2014) and task (Yogev-Seligmann et al. 2012). The capacity sharing model purports that pools of processing resources need to be divided amongst tasks during multitasking (Pashler and Johnston 1998; Tombu and Jolicoeur 2003). Prioritizing and allocating more cognitive resources towards one task leaves less cognitive capacity for the other task. This can lead to decrements in both tasks due to divided resources, but greater decrement in the one with less resources. Moreover, crosstalk between overlapping neural networks and executive functions required for walking and spelling backwards may also explain the decrements in both tasks during dual tasking (Pashler and Johnston 1998). In this study, decrements in velocity during dual task only occurred in older adults, suggesting that younger adults were better able to manage attentional demands required by the tasks unlike older adults. This finding may also be explained by task prioritization as an age-related difference between individuals. Literature suggested that older individuals utilize posture-first strategy, where they prioritize gait over cognitive task performance to prevent loss of balance (Berger and Bernard-Demanze 2011). However, there have also been reports of failing to following the posture-first strategy (Lindenberger et al. 2000; Corp et al. 2018), which is indicative of limitations of the cognitive resources.

Study limitations

This study has some limitations. The fNIRS used in the present study provides data on relative, rather than absolute, ΔO_2Hb unlike the frequency-and time-domain fNIRS. Moreover, the MoCA scores only showed a trend towards difference between younger and older adults indicating that the mean sample data didn't reflect significant cognitive impairment in older adults (Dale et al. 2018). A larger sample size and broader spread may provide the power to show the influence of this measure. Moreover, potential visual or auditory impairment may have influenced PFC ΔO_2Hb and impacted participants' performance during spelling and walking, thereby introducing bias in R. A future study may utilize an fNIRS device that enables measurements from a greater surface area of the head to provide insight into the activity of other neural regions (e.g., supplementary motor area, posterior occipital temporal areas) and networks (Mirelman et al. 2017; Papegaaij et al. 2017) in the cognitively impaired individuals during cognitive-motor tasks. Such data may then be utilized to devise appropriate rehabilitation interventions with focus on enhancing automaticity of walking.

Conclusions

Older adults had greater neural activity and greater dual task deficits in walking velocity than younger adults. Reduced dual task walking velocity and higher PFC ΔO_2Hb may indicate limited attentional resources with aging and suggest diminished automaticity. Individuals should be assessed at an earlier age to pre-habilitate and prevent functional decline that could increase risk of falls and other limitations in activities of daily living.

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Author contributions Conceptualization: WDR and LVB; methodology: WDR, LVB and DR; software, SAH; validation: all authors; formal analysis: SAH. WDR, DR; investigation: SAH, LVB and KTK; resources: WDR; data curation: SAH, KTK and WDR; writing—original draft preparation: SAH; writing—review and editing: all authors; visualization: SAH and WDR; supervision: WDR; project administration: all authors; funding acquisition: WDR. All authors have read and agreed to the published version of the manuscript.

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Availability of data and material The datasets of the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
Ethics approval
The study protocol was approved by the Research Ethics Board of University of Toronto (protocol ID: 33,466).

Consent to participate All participants provided written informed consent before participation.

Consent for publication All participants consented to having their data published and/or used in presentations.

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