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Obesity-specific neural cost of maintaining gait performance under complex conditions in community-dwelling older adults

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ABSTRACT

Background: Recent evidence of obesity-related changes in the prefrontal cortex during cognitive and seated motor activities has surfaced; however, the impact of obesity on neural activity during ambulation remains unclear. The purpose of this study was to determine obesity-specific neural cost of simple and complex ambulation in older adults.

Methods: Twenty non-obese and obese individuals, 65 years and older, performed three tasks varying in the types of complexity of ambulation (simple walking, walking + cognitive dual-task, and precision walking). Maximum oxygenated hemoglobin, a measure of neural activity, was measured bilaterally using a portable functional near infrared spectroscopy system, and gait speed and performance on the complex tasks were also obtained.

Findings: Complex ambulatory tasks were associated with ~2–3.5 times greater cerebral oxygenation levels and ~30–40% slower gait speeds when compared to the simple walking task. Additionally, obesity was associated with three times greater oxygenation levels, particularly during the precision gait task, despite obese adults demonstrating similar gait speeds and performances on the complex gait tasks as non-obese adults.

Interpretation: Compared to existing studies that focus solely on biomechanical outcomes, the present study is one of the first to examine obesity-related differences in neural activity during ambulation in older adults. In order to maintain gait performance, obesity was associated with higher neural costs, and this was augmented during ambulatory tasks requiring greater precision control. These preliminary findings have clinical implications in identifying individuals who are at greater risk of mobility limitations, particularly when performing complex ambulatory tasks.

1. Introduction

In the US, the number of individuals over the age of 65 years is expected to rise from 35 million to 71 million by 2030 (Yan, 2004). Approximately 30% of older adults fall at least once a year and over half of them experience repeated falls (Tinetti, 1988). In 2010, about 21,700 older adults died from unintentional falls, and by 2012, the direct medical cost of falls rose to $30 billion (CDC, 2010). Moreover, the incidence of non-fatal falls among older adult treated in the emergency departments was 2.5 million, and more than 734,000 of these patients were hospitalized (CDC, 2010). Among various factors, changes due to the normal aging process such as arthritis, poor balance and gait, reduced muscle mass and strength, obesity, impaired cognition, and visual impairment have all been associated with increased risk of falls in the elderly (Amboni et al., 2013; Tinetti, 1988).

Obesity, a pervasive condition in the geriatric population, is an important risk factor of falls in the elderly (Madigan et al., 2014). Obesity prevalence among older adults (~40%) is a growing concern as it adversely affects balance, gait, and posture (Fjeldstad et al., 2008). The chances of fall-related injuries requiring medical interventions are 15–79% higher for obese individuals than their lean counterparts (Finkelstein et al., 2007, 2010). Obesity impairs balance and gait due to biomechanical demands of added body mass (Dutil et al., 2013), but it has also shown to weaken sensory processing and psychomotor abilities that are critical during walking while multitasking (Mignardot, 2010). Declines in executive functioning and visual-motor skills are observed with obesity in older individuals (Wolf et al., 2007), which has been attributed, in part, to decreased gray matter volume in the orbitofrontal cortex that controls executive functions and the right cerebellum area that contributes significantly to motor control (Gunstad et al., 2008; Raji et al., 2010; Taki, 2008).

Obesity at midlife has been linked with impaired cognition, increased dementia risk, and accelerated cerebral atrophy in older adults (Gustafson et al., 2004; Whitmer, 2008). In young adults, recent cross-sectional studies have linked obesity-related decrements in motor and cognitive performance to impaired functioning of the prefrontal cortex (PFC) (Gonzales et al., 2014; Mehta, 2015a; Mehta and Shortz, 2014).

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This is particularly concerning, as recent neuroimaging studies have established the role of the PFC in regulating single and dual-task balance and gait functions (Amboni et al., 2013; Mirelman, 2014). It is thus possible that obesity, through changes in PFC function, may adversely affect gait function during simple and complex tasks. Understanding obesity-related changes in PFC functions during gait, along with traditional biomechanical gait analyses, can provide more information regarding the susceptibility of this population to falls and thus warrants further investigation.

Complex secondary tasks, such as mental tracking, reaction time, verbal fluency, and manual tasks, have been previously employed to evaluate dual-task gait scenarios in older adults (Faulkner et al., 2007; Herman et al., 2010; Lundin-Ohson et al., 1998; Yamada, 2011). For example, gait pattern changes in old age are more noticeable when walking is combined with a secondary visual task (Beurskens and Bock, 2012; Beurskens et al., 2014). There is general consensus regarding age-related reduction in PFC activity during complex walking tasks in the elderly (Beurskens et al., 2014; Holtzer et al., 2011a, 2011b). Despite increasing biomechanical evidence that obesity is a risk factor for falls in the elderly and emerging evidence of obesity-related impairments in brain function, to our knowledge, no study has compared the difference in PFC activation in obese and non-obese older adults during balance and gait, particularly during dual-task scenarios. This is a critical barrier to the development of clinical indicators to identify individuals who are at greater risk of mobility limitations due the normal aging process compounded with obesity.

Neuroimaging techniques have been instrumental in understanding the contributions of brain regions to perform cognitive tasks and static motor tasks (Liu et al., 2000; Mehta and Parasuraman, 2014). However, imaging methods such as functional magnetic resonance imaging and positron emission tomography are limited in their abilities to provide functional brain imaging during walking tasks. Functional near infrared spectroscopy (fNIRS), an optical imaging technique, is non-invasive and portable and provides measures of cerebral oxy- and deoxy-hemoglobin levels that reflect changes in neuronal input and/or processing during cognitive and motor activities (Ayaz et al., 2010, 2012; Mehta and Shortz, 2014; Mehta and Parasuraman, 2013, 2014). It offers good temporal resolution and permits evaluation of movement-based motor activities with relative ease and has been successfully employed during dual task walking tasks in healthy younger and older adults (Beurskens et al., 2014; Holtzer et al., 2011a, 2011b; Mirelman, 2014). The objective of the study was to determine the obesity-specific activation of the prefrontal cortex using fNIRS during simple and complex ambulatory tasks in older adults. It was hypothesized that PFC activity will differ with obesity in older adults and that this difference will be augmented during complex tasks when compared to the simple ambulatory tasks.

2. Methods

2.1. Participants

Ten non-obese (8 females and 2 males) and ten obese (6 females and 4 males) individuals 65 years or older were recruited from a local senior living community. Obesity was defined based on body mass index (BMI >30 kg/m^2 for obese and <25 kg/m^2 for non-obese), and additionally, waist circumference (WC >102 cm for men and >88 cm for women) and body fat percentage were used as confirmatory measures (body fat percent >40% for female and >25% for male) (Gallagher et al., 2000). Significant group-level differences in WC and body fat percentage support that BMI differences were due to obesity but not other confounding factors such as high muscularity (NIH et al., 2000). The demographic and biometric descriptions of participants are presented in Table 1. The selection of participants was restricted to those who were ambulatory without any aid (such as walker or cane) with no self-reported musculoskeletal, cardiovascular, neurological, and cognitive disorders. Informed consent using procedures approved by the Texas A&M University Institutional Review Board was obtained prior to the experiment.

Table 1
Summary data from the two participant groups (mean (SD)).

	Non-obese ($n = 10$)	Obese ($n = 10$)	*P*-value
Age (years)	80.6 (7.50)	80.5 (6.79)	0.978
Body mass (kg)	66.17 (9.04)	88.28 (15.67)	0.008
Stature (m)	1.69 (0.06)	1.651 (0.12)	0.118
BMI (kg/m^2)	23.74 (2.61)	32.19 (3.98)	<0.0001
Waist circumference (cm)	86.3 (8.04)	112.7 (10.36)	<0.0001
Body fat (%)	32.74 (8.04)	40.38 (6.59)	0.045
Falls in the past year	2.33 (2.3)	1.0 (1.0)	0.541

2.2. Experimental design

A group (non-obese and obese) × task (quiet seated, simple walking, walking + cognitive dual task (CDT), and precision walking (PW)) mixed measures design was employed to determine the effect of obesity on PFC activity during ambulation in older adults. Participants in each obesity group performed all four tasks, and the task order was counterbalanced in each group to avoid fatigue and/or learning effects.

2.3. Procedures

Participants attended one experimental session at the local senior living community where data were being collected. Body composition and anthropometric measurements, namely, percent body fat, weight, height, waist and hip circumference were recorded at the start of the session. Data were collected in the senior living facility in a long hallway that was assigned to the experiment and resident seniors were requested to use a secondary hallway to avoid interruptions and distractions during experimentation. Upon providing written consent, participants were familiarized with the secondary tasks, such as recitation of alphabets and practicing precision walking based on the track provided on the floor. Following task familiarization, they were instrumented with biosensors that measured prefrontal cortex activity bilaterally and heart rate that are described later.

Once instrumented, assessment of falls risk was determined using the Stopping Elderly Accidents, Deaths and Injuries (STEADI) tool kit that included the Timed Up and Go (TUG) test, Chair Stand Test (CST), and the four-stage balance test to assess functional mobility, leg strength, and balance, respectively (CDC, 2014). The TUG test involved rising from a chair and walking a distance of 3 m, turning around, walking back to the chair, and sitting down. Participants were encouraged to walk at their comfortable pace, and the total time taken was recorded. An older adult who takes ≥12 s to complete the TUG is at high risk for falling (CDC, 2014). In the CST, using a chair without an armrest, participants rose to a full standing position then sat back again while their arms were across the chest, and the total number of times they stood up in 30 s was recorded. A below average score, which is gender- and age-dependent (CDC, 2014), indicates a high risk for falls. In the four-stage balance test, participants stood in 4 postures: (1) with their feet side by side, (2) with the instep of one foot touching the big toe of the other, (3) with one foot in front of the other with heel touching toe (tandem), and (4) standing on one foot. Participants were instructed to assume each posture for 10 s with arms held out without moving their feet, and the time (if less than 10 s) that they could hold that balance posture was recorded. An older adult who cannot hold the tandem stance for at least 10 s is at increased risk of falling (CDC, 2014).

Upon completion of the falls risk assessment, a quiet seated task was performed that required participants to sit comfortably in a chair for 30 s. Each participant then performed two blocks of simple and complex walking tasks (Fig. 1). Each block consisted of 4 trials of 30 s each, with 10 s of quiet standing in between each trial, and the blocks were