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The effect of lower limb muscle fatigue on obstacle negotiation during walking in older adults

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ABSTRACT

Tripping over obstacles is a common cause of falls in older adults, and muscle fatigue, which can alter walking patterns, may add to this risk. To date, no study has examined the effect of lower limb muscle fatigue on obstacle negotiation in older adults. 30 older adults (13 women, aged 78.3 [6.2] years) negotiated a 12 m obstacle course, while completing a visual secondary task, under two randomized conditions: rested or fatigued. For the fatigue condition, participants performed a repeated sit-to-stand movement, as fast as possible, until they could no longer continue. Participants then immediately began walking trials. Kinematic and kinetic data were collected on approach to, during, and after crossing a height-adjustable target obstacle (10% and 20% of leg length). Repeated measures ANOVA showed a statistically significant increase in lead limb vertical loading rate after stepping over the 10% obstacle when fatigued, relative to rested ($P = 0.046$). No other significant between-condition differences (>0.05) were observed for the other kinematic variables when negotiating the 10% obstacle. Furthermore, no significant between-condition differences ($P > 0.05$) were observed for any kinetic or kinematic variables when negotiating the 20% obstacle. This study describes a feasible method for investigating the consequences of lower limb muscle fatigue on obstacle crossing. The current finding of increased vertical loading rate when fatigued supports the need for further investigation into the effect of muscle fatigue on gait under different environmental conditions, fatiguing a range of muscles, analyzing a more comprehensive array of kinetic and kinematic measures, and in healthy and clinical populations.

1. Introduction

Tripping over obstacles commonly causes older people to fall when walking in challenging environments, accounting for 35–53% of all falls in community-dwelling older people [1]. Previous work has explored obstacle avoidance during walking in a range of older population groups including healthy older people [2–7], older fallers [7–9], and people with Parkinson's disease [10], stroke [11], and knee osteoarthritis [12]. Successful obstacle avoidance may be compromised by age-related declines in physical function or alterations in motor control strategies [13,14].

Muscular fatigue can lead to a loss of muscle strength, which may compromise obstacle clearance. Evidence from a recent systematic review suggests muscle fatigue can impair standing balance, and functional task performance, specifically response to external perturbation and voluntary movements, in older people [15]. However, only two studies have experimentally investigated the effect of lower limb muscle fatigue on walking in older people [16,17].

Helbostad et al. [17] concluded that after performing a fatiguing repeated sit-to-stand task, older adults took significantly wider steps, showed greater step length variability and alterations in trunk acceleration during level-ground walking, compared to when rested [17]. The direction of change in these gait variables suggests fatigue may reduce dynamic stability, leading to characteristic walking patterns seen in frail older adults [18,19]. In contrast and surprisingly, Granacher et al. [16] reported that fatigue of the knee extensors (following an isokinetic exercise protocol) in older people, significantly increased gait velocity and stride length and reduced stride length variability under dual-task walking conditions. These conflicting studies [16,17] suggest more research is required to understand the effects of lower limb muscle fatigue on walking in older people under single and dual-task conditions. It also remains unknown whether lower limb muscle fatigue affects obstacle avoidance in older people – an important strategy for avoiding tripping in challenging environments.

This study investigated the effects of exercise-induced lower limb muscle fatigue on obstacle negotiation in older people. A visual secondary task was used to emulate a situation encountered during daily life, i.e. navigating through a

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challenging and distracting environment such as a shopping mall or busy street. Previous research has shown that a visual secondary task is necessary to induce obstacle contacts in a laboratory situation [5]. We hypothesized that in negotiating an obstacle, lower limb muscle fatigue would result in: (i) reduced foot clearance; (ii) slower crossing velocity; and (iii) altered limb loading post-obstacle clearance.

2. Methods

2.1. Participants

Community-dwelling men and women aged over 70 years were recruited from a volunteer database and advertising at community group meetings. Exclusion criteria included self-reported neuromuscular disease, recent injury to the back or legs, unstable psychiatric conditions, inability to walk 12 m unassisted, and cognitive impairment (Mini-Mental State Examination [MMSE] score <24) [20]. All participants gave written informed consent. Ethical approval was granted by the University of New South Wales Human Research Ethics Committee.

2.2. Baseline assessment

Participants completed a short questionnaire detailing current health status. Sensorimotor function, risk of falling, and concern about falling were assessed using the Physiological Profile Assessment [21] and Iconographical Falls Efficacy Scale [22].

2.3. Equipment

Kinematic data were collected using two CODA scanner units (Model cx1, Codamotion, Charnwood Dynamics Ltd., Rothley, UK) at a sampling rate of 200 Hz. Kinetic data was obtained from a Kistler force platform (Model 9286AA, Kistler, Alton, UK) at 1000 Hz.

2.4. Procedures

All participants negotiated a 12 m obstacle course, while completing a visual secondary task, under two randomized conditions: rested (control) and fatigued. The 12 m walking path comprised 7 obstacles made from foam and cardboard (smallest [width (distance across the walkway) × height × length]: 53 × 0.5 × 3 cm; largest: 110 × 18 × 6 cm), placed at irregular intervals along the walkway (ranging from 0.80 to 2.15 m apart). The sixth obstacle along the walkway was height-adjustable. This 'target' obstacle was set to two different height conditions: 10% and 20% of each participant's leg length (distance from the anterior superior iliac spine to the lateral malleoli of the dominant leg). These heights were chosen based on previous protocols [4,12,23] and represented obstacle dimensions commonly encountered in daily life such as paving curbs [23]. The target obstacle was located directly before a force platform so participants' lead limb would land on the force platform after crossing the obstacle. The order of target obstacle height presentation was randomized within-session.

Participants wore low-cut ankle socks and Oxford-style lace-up shoes of the appropriate size with a suede upper and nitrile rubber sole during testing. Active markers were attached bilaterally onto the toe box, fifth metatarsal head, most posterior position on the left heel (facing laterally) and right heel (facing medially), left lateral malleolus, right medial malleolus, and top surface of the target obstacle. Prior to testing, the investigator ensured marker wire connections did not impede walking ability.

2.4.1. Walking task

At the starting line, participants received standardized instructions to walk at their preferred speed, step over the obstacles, and were encouraged not to stop during trials. Following a practice trial, participants navigated the walkway six times for each obstacle height for a total 12 consecutive trials per session. Participants were instructed to commence each gait trial by stepping with the same foot, to ensure they crossed the target obstacle with the same lead limb. Fig. 1 illustrates the kinematic measures collected. Vertical loading rate of the lead limb, after stepping over the target obstacle, was calculated from the vertical force recorded over the first 100 ms of foot contact with the force platform and normalized to subjects' body mass (expressed in N kg^{-1} s^{-1}) [24]. A threshold of 10 N was used to identify onset of foot contact [25]. Vertical loading rate was normalized to walking velocity (expressed in N kg^{-1} m^{-1}) [24] to ensure any significant differences in kinetic variables between rested and fatigue conditions were not caused by variations in walking velocity.

2.4.2. Visual secondary task

Whilst negotiating the obstacle course, participants were required to regularly look up and read aloud a sequence of 10 monosyllabic letters (C, D, E, F, L, N, O P, T and Z) from a computer screen positioned at eye level at the end of the walkway (12.5 m from the start). Letters were displayed in Arial font (height: 261 mm, width: 224 mm and limb thickness: 34 mm), and presented for 1.5 s, followed by a blank screen presented for 2 s break. An auditory cue signaled the presentation of each letter [5].

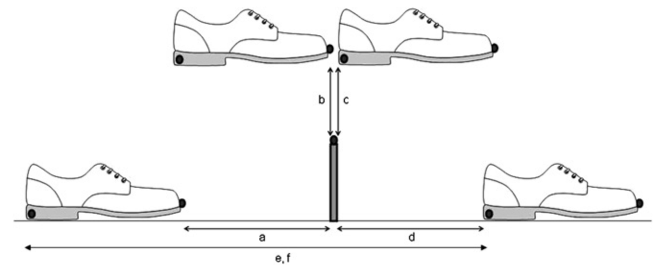

Fig. 1. Kinematic measures collected on approach to, during, and after crossing the target obstacle set to 10% and 20% of leg length. (a) Trail limb approach distance (*trail limb toe-obstacle horizontal distance on approach*) (cm). (b) Trail limb toe clearance (*trail limb toe-obstacle vertical distance at toe crossing*) (cm). (c) Lead limb heel clearance (*lead limb heel-obstacle vertical distance at heel crossing*) (cm). (d) Lead limb landing distance (*lead limb heel-obstacle horizontal distance after stepping over obstacle*) (cm). (e) Obstacle crossing stride length (*horizontal distance between trail limb heel contact on approach to obstacle and trail limb heel contact after stepping over obstacle*) (cm). (f) Obstacle crossing velocity (*stride length over obstacle/obstacle crossing time*) (m s^{-1}).

2.4.3. Fatigue protocol

The term fatigue was defined as '*the observation of a decrement in performance following exercise*' [15]. Participants sat on a 66 cm hardback chair. A Velcro strap, to which a digital strain gauge was connected, was attached to the participant's leg, 10 cm above the lateral malleolus of the dominant lower limb. Participants extended their knee as hard as they could against the resistance of the strap. This procedure was repeated three times to generate a measure of pre-fatigue quadriceps muscle strength. Participants then transferred to a 46 cm hardback chair and were instructed to cross their arms and repeatedly stand up and sit down as fast as possible (while receiving verbal encouragement), until they could no longer continue [17]. The number of sit-to-stand repetitions was counted and timed. Immediately after the participant indicated they could no longer continue, quadriceps muscle strength was re-assessed. Participants then immediately began walking trials. Rested and fatigued conditions were randomly presented and performed on two separate occasions, approximately one week apart, providing sufficient recovery time for those who completed the fatigued trials first.

2.5. Statistical analysis

Data were analyzed with SPSS (Chicago, IL, USA) version 18.0.0. For each variable, a repeated measures analysis of variance (ANOVA) was conducted to determine the within-subject effects of lower limb muscle fatigue (for the 10% and 20% obstacles) on kinematic and kinetic variables. Rested obstacle crossing velocity (for each obstacle height), was included as a covariate. The alpha was set at 0.05 with Bonferroni adjustments for multiple comparisons.

3. Results

Of the 43 participants recruited, 3 were excluded prior to data collection, one due to ill health and two were unable to walk 12 m unassisted. Following data collection, 10 participants were excluded from the final analysis, as they showed no decrement in quadriceps muscle strength after performing the fatiguing task. Table 1 shows basic demographic, health, and sensorimotor function measures, for the 30 included participants.

In the current study, older people walked at a mean (SD) velocity of 0.95 (0.25) m s^{-1} and 0.88 (0.24) m s^{-1}, when crossing the low-level and high-level target obstacles during the rested condition, respectively. These data suggest the functioning level of healthy older participants in the current study concurs with previous research strategies investigating obstacle crossing in healthy older people (mean crossing speed 0.82–2.16 m s^{-1}) [6].

3.1. Fatiguing task

The mean (SD) number of sit-to-stand repetitions performed was 62.5 (39.6), range 23–202, in a duration of 154.1 (108.3) s.