Journal of Biomechanics 49 (2016) 238–243

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Muscle weakness is related to slip-initiated falls among community-dwelling older adults

Li Ding [a], Feng Yang [b,*]

[a] School of Biological Science and Medical Engineering, Beihang University, Beijing 100191, China
[b] Department of Kinesiology, University of Texas at El Paso, 1851 Wiggins Rd, Rm-452, El Paso, TX 79968, USA

ARTICLE INFO

Article history:
Accepted 4 December 2015

Keywords:
Fall prevention
Treadmill
Lower extremity
Standardized fall-induction

ABSTRACT

The purposes of this study were (1) to investigate the relationship between muscle weakness and slip-related falls among community-dwelling older adults, and (2) to determine optimal cut-off values with respect to the knee strength capacity which can be used to identify individuals at high risk of falls. Thirty-six healthy older adults participated in this study. Their muscle strength (torque) was assessed at the right knee under maximum voluntary isometric (flexion and extension) contractions. They were then moved to a special treadmill. After walking regularly five times on the treadmill, they experienced an identical and unannounced slip during walking on the treadmill with the protection of a safety harness. This treadmill could be considered a *standardized* platform, inducing an unexpected slip. Accuracy of predicting slip outcome (fall vs. recovery) was examined for both strength measurements (i.e., the strength capacity of knee extensor and flexor) using univariate logistic regressions. The optimal cutoff values for the two strength measurements were determined by the receiver operating characteristic analysis. Results showed that fallers displayed significantly lower knee strength capacities compared to their recovery counterpart (1.10 vs. 1.44 Nm/kg, $p < 0.01$, effect size Cohen's $d = 0.95$ for extensor; 0.93 vs. 1.13 Nm/kg, $p < 0.05$, $d = 0.69$ for flexor). Such results suggested that muscle weakness contributes to falls initiated by a slip during gait. Our findings could provide guidance to identify individuals at increased risk of falling using the derived optimal cutoff values of knee strength capacity among older adults.

1. Introduction

Falls are a significant health and medical problem facing the growing population of elderly (Tinetti, 2003). Slip-related falls contribute about 40% of all outdoors falls among seniors, which often cause serious injuries such as hip fractures (Luukinen et al., 2000; Stevens et al., 2006). Logically, it is urgent to understand the causes contributing to falls in order to develop efficient fall risk assessment tools and to design effective interventions for reducing falls.

Though it is well accepted that aging is associated with a progressive decline in overall mechanical muscle function (Goodpaster et al., 2006; Skelton et al., 2002) and muscle weakness has been implicated as a risk factor for falls, sound evidence regarding the extent to which the muscle weakness directly and independently relates to falls in older adults is largely lacking. The causal-effect relationship between muscle weakness and falls among older adults is still unclear. It was reported in one study that older fallers demonstrated less muscular strength (−15%) than their non-faller counterpart (Perry et al., 2007). A meta-analysis also concluded that muscle weakness should be one of risk factors leading to falls in older adults (Moreland et al., 2004). However, other studies showed minimal or no differences in strength between fallers and non-fallers (Daubney and Culham, 1999; Lipsitz et al., 1994; Skelton et al., 1994). A recent review article suggested that the evidence for the cause and effect link between muscle function and balance performance in older population is still weak (Orr, 2010).

Several possible reasons could contribute to such inconclusive causal-effect connections between muscle weakness and falls. First, the traditional self-report method collecting the real-life falls utilized in previous studies is subjected to inaccuracy, bias, and omission resulting from deteriorated memory or cognitive dysfunction in seniors (Moreland et al., 2004), and decreasing the reliability of data on fall incidence (Jenkins et al., 2002). Second, the physical activity level and the exposure to possible fall hazards are factors affecting the likelihood of falling in older adults. The self-report method does not account for these factors, possibly leading to underestimation of actual fall counts (Graafmanc et al.,

* Corresponding author. Tel.: +1 915 747 8228; fax: +1 915 747 7522.
E-mail address: fyang@utep.edu (F. Yang).

http://dx.doi.org/10.1016/j.jbiomech.2015.12.009
0021-9290/

2003; Wijlhuizen et al., 2010). There could be a trade-off between the exposure to fall hazards and the risk of falls among older adults (Horlings et al., 2008). For instance, those who are physically inactive might be more prone to falls due to physical limitations, but may also have the least exposure to conditions that might induce falls; while the most active ones, who might be less prone to falls, have high exposure to fall hazards leading to high likelihood of falling. Third, the self-reported data often lack information on the specific details (like types and circumstances of falls) of the actual falls (Feldman and Robinovitch, 2006), which could vary considerably from person to person. For example, muscle strength may not be as effective for the falls resulting from dizziness or orthostatic hypotension as for falls caused by external perturbations (such as slips or trips). Without considering or controlling for the circumstances of falls and level of the exposure to fall hazards, it is very difficult, if not impossible, to precisely investigate the relationship between muscle weakness and falls.

Last, the (retrospective or prospective) falls collection using self-reported methods were usually a significant period (like months) away from the evaluation of muscle strength (Horlings et al., 2008; Moreland et al., 2004). As muscle strength/power decline is a serious problem among older adults (Goodpaster et al., 2006; Skelton et al., 2002), the muscle strength measured could be substantially different from the one at the instant when the fall occurs. This mismatch raises another major concern as to how accurately the findings derived from the information collected at different time instants reflect the real causal-effect linkage between fall incidences and the muscle weakness. The only way to truly quantify the relationship between muscle weakness and falls is to evaluate how all subjects respond to the same gait perturbation administered in a controlled laboratory condition and to evaluate the muscle strength performance at the same time as the laboratory-induced falls.

Treadmills with the capability of exerting external perturbations on human gait have been broadly used in fall-prevention related studies towards both healthy adults and individuals with movement disorders. For instance, special treadmills were employed to improve balance compensatory responses during walking in young (Yang et al., 2013) and older persons (Shapiro and Melzer, 2010). In another study, an incremental speed-dependent treadmill was used to reduce postural instability and fear of falling in persons with Parkinson's disease (Cakit et al., 2007). These treadmills can produce a simulated perturbation (either slip or trip) by suddenly altering the belt speed when the subject is walking on it. The change in the belt speed can be delivered in a precisely-controlled manner. As a result, the intensity of the perturbation is identical across different trials and different subjects. Therefore, this type of treadmill provides a standardized platform inducing the same gait perturbations for different subjects. A standardized technique of creating slip perturbation allow us to eliminate the effects of other possible confounding factors (like the circumstance of a fall, duration between a fall and muscle function evaluation, etc.) on falls.

The purposes of this study were (1) to investigate the relationship between muscle weakness and slip-related falls among community-dwelling older adults, and (2) to determine optimal cutoff values with respect to the knee strength capacity which can be used to identify individuals at high risk of falls. After being measured for their muscle strength, all subjects were exposed to an identical risk of slip-related falling during gait upon a treadmill. We hypothesized that those who fell in response to the unexpected slip would demonstrate less knee muscle strength capacity compared with their recovery counterpart. The findings from this study could provide some guidance to develop effective muscle-strengthening-based fall-prevention training paradigms.

Table 1
The demographics and self-selected gait speed in mean ± SD for both groups (fall vs. recovery).

Groups	Recovery (n=19)	Fall (n=17)	Pooled (n=36)
Age (years)	70.7 ± 4.8	71.9 ± 4.8	71.3 ± 4.7
Gender (male)	12 (63.2%)	5 (29.4%)	17 (47.2%)
Height (cm)	168.1 ± 9.7	161.7 ± 11.3	165.1 ± 10.8
Mass (kg)	77.3 ± 11.7	74.5 ± 21.8	76.0 ± 17.0
Self-selected gait speed (m/s)	0.97 ± 0.26	0.80 ± 0.23	0.89 ± 0.25

2. Methods

2.1. Subjects and experimental protocol

Thirty-six healthy older adults (71.3 ± 4.7 years, Table 1) participated in the experiment. All participants were free of any clinically significant history of musculoskeletal disorders, neurological disorders, orthopedic conditions, and cardiovascular conditions. As a safety precaution, all subjects were also screened for a significant cognitive impairment (Folstein et al., 1975) and an elevated risk of

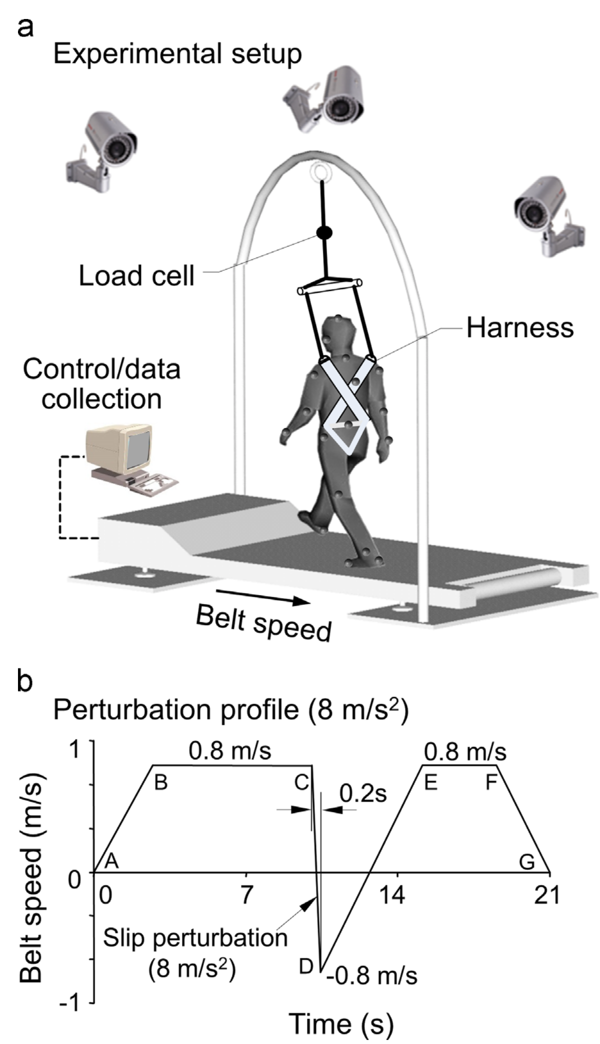

Fig. 1. Schematics of (a) the treadmill used to produce slip-like perturbation, and (b) a representative profile of the treadmill perturbation for a slip trial with the self-selected walking speed of 0.8 m/s and an acceleration of 8 m/s^2. The slip trial began with a 2-s ramp up (point A to B), followed by a steady state with a backward-moving belt speed of 0.8 m/s (B to C). After 10–12 regular steps in the slip trial, approximately 80–120 ms later than the touchdown of the leading foot, the top belt was suddenly accelerated forward within 0.2 s (point C to D) without the subjects' knowledge. Following the slip perturbation, the top belt speed slowly returned to backward direction at 0.8 m/s (point D to E). Subjects are protected by a full-body safety harness during all trials on the treadmill. Full-body kinematics is collected by a motion capture system from 26 reflective markers affixed to subjects' body.