Available online at www.sciencedirect.com

ScienceDirect

Clinical Biomechanics 22 (2007) 689–696

CLINICAL BIOMECHANICS

www.elsevier.com/locate/clinbiomech

Maximum Step Length: Relationships to age and knee and hip extensor capacities

Brian W. Schulz [a,b,c,d,*], James A. Ashton-Miller [b,d], Neil B. Alexander [c,d,e]

[a] *Patient Safety Center, James A. Haley Veterans Hospital, 11605 North Nebraska Avenue, Tampa, FL 33612-5738, USA*
[b] *Department of Biomedical Engineering, Biomechanics Research Laboratory, MI, USA*
[c] *Department of Internal Medicine, Division of Geriatric Medicine, Mobility Research Center, USA*
[d] *Institute of Gerontology, University of Michigan, Ann Arbor, MI, USA*
[e] *VA Ann Arbor Health Care System Geriatrics Research Education and Clinical Center (GRECC), USA*

Received 13 July 2006; accepted 21 February 2007

Abstract

Background. Maximum Step Length may be used to identify older adults at increased risk for falls. Since leg muscle weakness is a risk factor for falls, we tested the hypotheses that maximum knee and hip extension speed, strength, and power capacities would significantly correlate with Maximum Step Length and also that the "step out and back" Maximum Step Length [Medell, J.L., Alexander, N.B., 2000. A clinical measure of maximal and rapid stepping in older women. J. Gerontol. A Biol. Sci. Med. Sci. 55, M429–M433.] would also correlate with the Maximum Step Length of its two sub-tasks: stepping "out only" and stepping "back only". These sub-tasks will be referred to as versions of Maximum Step Length.

Methods. Unimpaired younger ($N = 11$, age = 24[3] years) and older ($N = 10$, age = 73[5] years) women performed the above three versions of Maximum Step Length. Knee and hip extension speed, strength, and power capacities were determined on a separate day and regressed on Maximum Step Length and age group. Version and practice effects were quantified and subjective impressions of test difficulty recorded. Hypotheses were tested using linear regressions, analysis of variance, and Fisher's exact test.

Findings. Maximum Step Length explained 6–22% additional variance in knee and hip extension speed, strength, and power capacities after controlling for age group. Within- and between-block and test–retest correlation values were high (>0.9) for all test versions.

Interpretation. Shorter Maximum Step Lengths are associated with reduced knee and hip extension speed, strength, and power capacities after controlling for age. A single out-and-back step of maximal length is a feasible, rapid screening measure that may provide insight into underlying functional impairment, regardless of age.

Keywords: Step length; Strength; Moment; Speed; Power; Dynamometer; Falls; Biomechanics

1. Introduction

Falls are a leading cause of accidental death and injury for those over the age of 65 years (CDC, 2000). Older women, especially those with balance impairments, are at a particularly high risk for fall-related injuries (Baker et al., 1992). The ability to recover from an imminent fall has been shown to be dependent on the ability to take an adequately rapid and long recovery step in the direction of the fall (Alexander, 1994; Luchies et al., 1994; Maki and McIlroy, 1999; Thelen et al., 1997).

In one measure of volitional stepping ability, Medell and Alexander (2000) instructed subjects to step out as far as possible and return to the original stance position in one step. This Maximum Step Length (MSL) was found to decline with age and balance impairment and to correlate strongly with measures of balance, fall risk, mobility

---

[*] Corresponding author. Address: Patient Safety Center, James A. Haley Veterans Hospital, 11605 North Nebraska Ave., Tampa, FL 33612-5738, USA.
E-mail address: Brian.Schulz@va.gov (B.W. Schulz).

0268-0033/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2007.02.008

performance, and self-reported disability in balance-impaired older adults (Cho et al., 2004; Medell and Alexander, 2000). Compared to other gait and balance measures, an alternative version of MSL that did not require returning to the start position in one step showed the greatest decline from the third to the ninth decade of life, even when adjusted for body anthropometry (Lindemann et al., 2003). MSL test–retest reliability is satisfactory and, while MSL was originally conducted in three directions (forward, sideways, and backwards) with both right and left feet, a simplified version more appropriate for clinical settings (right foot-forward only) is equally predictive of the above functional outcomes (Cho et al., 2004) and will be employed here.

MSL thus appears to be a measure of fall risk as well as other mobility-related factors. Yet, as in many clinical mobility tests, little is known about the mechanisms underlying variations in MSL. The central question addressed in the present paper is: "Does MSL tell us anything about an individual's leg speed, strength, or power capacities independent of their age?".

Most tests of volitional stepping (Lord and Fitzpatrick, 2001; Luchies et al., 2002; Patla et al., 1993; White et al., 2002) evaluate only step timing and do not take into account step distance (Cronin et al., 2003; Lord and Fitzpatrick, 2001; Luchies et al., 2002, 1999; White et al., 2002). Greater step distances likely place greater physiological demands on the hip and knee musculature. Given that strength (Brooks and Faulkner, 1994; Doherty et al., 1993; Frontera et al., 1991; Hakkinen et al., 1996; Lexell, 1995), power (Hakkinen et al., 1997; Izquierdo et al., 1999; Macaluso and De Vito, 2003; Metter et al., 1997; Smeesters et al., 2002; Whipple et al., 1987), and peak contraction velocity (Hortobagyi et al., 1995; Larsson et al., 1979; Pousson et al., 2001) decline with age, might these declines be related to the age-related decline in MSL (Cho et al., 2004; Lindemann et al., 2003; Medell and Alexander, 2000)?

Although the length and timing of perturbation-elicited steps (King et al., 2005; Wojcik et al., 1999), the timing of volitional steps (Lord and Fitzpatrick, 2001; Luchies et al., 2002), and the lower extremity strength required to recover from a forward fall (Madigan and Lloyd, 2005; Pijnappels et al., 2005; Wojcik et al., 2001) have been quantified, we are not aware of published studies relating maximal volitional step length to lower-limb strength and power.

The primary goal of this study was to determine if decrements in knee and hip extensor muscle capacities correlate with shorter MSL independent of age group. We also sought to detect differences in performance on the original MSL and on its sub-tasks, i.e. stepping out only and thus omitting the return step as per (Lindemann et al., 2003), or starting in an outstretched position, after which only the return step was executed. These two sub-tasks will be fully explained in the Methods and will henceforth be referred to as MSL versions.

We hypothesized that the original MSL will (a) explain a significant amount of variance in the knee and hip extension speed, strength, and power capacities after controlling for age group, and (b) significantly correlate with both other MSL versions. We also hypothesized that (c) all MSL versions would have sufficient reliability as indicated by within- and between-block intraclass correlation coefficients (ICC > 0.90) to base decisions upon (Nunnally and Bernstein, 1994). Exploratory data were also collected on subjective perceptions of difficulty between the three MSL versions and within specific portions of the original MSL.

If MSL is related to knee and hip extensor capacities (hypotheses a) it might prove to be a rapid, age-independent screening measure of lower-limb function. If different MSL versions correlate with each other (hypothesis b), then the specific version used may not alter the clinical utility of the MSL. If ICC values are sufficiently high, then only a single trial may be required to obtain a valid and reliable MSL.

2. Methods

2.1. Subjects

Eleven younger (mean [SD] age = 24[3.4] years) and ten older (mean age = 73[5.3] years) unimpaired females participated in this study. All younger subjects completed a medical questionnaire and all older subjects were physically screened by a geriatric nurse–clinician supervised by the physician–geriatrician prior to testing. The older women had no significant abnormal neurological or musculoskeletal findings on directed history and physical. The two groups were of similar stature, but the younger women weighed less than the older women ($P = 0.008$ for weight and $P = 0.003$ for body mass index, Table 1). All subjects wore their own athletic shoes for the MSL testing.

2.2. MSL instrumentation and protocol

Three versions of MSL were evaluated in this study- the original MSL and its two sub-tasks. Only the right leg was tested and trials were considered an error if more than a single step was used (due to a loss of balance), the arms

Table 1
Mean (SD) subject characteristics and Maximum Step Length (MSL) for all three MSL versions

	Younger women	Older women
Number of subjects	11	10
Mean age (years)*	24 (3)	73 (5)
Height (cm)	163 (7)	160 (5)
Mass (kg)†	55.0 (5.1)	68.4 (14.1)
Body mass index (kg/m^2)†	20.7 (3.2)	26.7 (3.6)
MSL – "Out & Back" (% height)*	78.5 (5.4)	57.8 (9.1)
MSL – "Out Only" (% height)*	84.0 (8.2)	62.2 (10.3)
MSL – "Back Only" (% height)*	75.4 (3.2)	54.8 (9.6)

* Indicates age group effect $P < 0.0001$.
† Indicates age group effect $P < 0.01$.