Clinical Biomechanics 28 (2013) 933–940

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Effects of step length, age, and fall history on hip and knee kinetics and knee co-contraction during the maximum step length test

Brian W. Schulz [a,b,*], Manutchanok Jongprasithporn [a,c], Stephanie J. Hart-Hughes [b], Tatjana Bulat [b]

[a] HSR&D/RR&D Center of Excellence in Maximizing Rehabilitation Outcomes, James A. Haley VA Hospital, Tampa, FL, USA
[b] Patient Safety Center of Inquiry, James A. Haley VA Hospital, Tampa, FL, USA
[c] Grado Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA

ARTICLE INFO

Article history:
Received 12 June 2013
Accepted 1 August 2013

Keywords:
Biomechanics
Stepping
Kinetics
Strength
Co-contraction
Coactivation
Older adults
Fallers

ABSTRACT

Background: Maximum step length is a brief clinical test involving stepping out and back as far as possible with the arms folded across the chest. This test has been shown to predict fall risk, but the biomechanics of this test are not fully understood. Knee and hip kinetics (moments and powers) are greater for longer steps and for younger subjects, but younger subjects also step farther.
Methods: To separate the effects of step length, age, and fall history on joint kinetics; healthy younger (age=27(5), N=14), older non-fallers (age=72(5), N=14), and older fallers (age=75(6), N=11) all stepped to the same relative target distances of 20–80% of their height. Knee and hip kinetics and knee co-contraction were calculated.
Findings: Hip and knee kinetics and knee co-contraction all increased with step length, but older non-fallers and fallers utilized greater stepping hip and less stepping knee extensor kinetics. Fallers had greater stepping knee co-contraction than non-fallers. Stance knee co-contraction of non-fallers was similar to young for shorter steps and similar to fallers for longer steps.
Interpretation: Age had minimal effects and fall history had no effects on joint kinetics of steps to similar distances. Effects of age and fall history on knee co-contraction may contribute to age-related kinetic differences and shorter maximal step lengths of older non-fallers and fallers, but step length correlated with every variable tested. Thus, declines in maximum step length could indicate declines in hip and knee extensor kinetics and impaired performance on similar tasks like recovering from a trip.

Published by Elsevier Ltd

1. Introduction

Nearly half (47.9%) of all injury-related deaths in persons over the age of 65 are due to falls and non-fatal injuries due to falls in this population are nearly twice (1.9×) as frequent as injuries from all other causes combined (CDC, 2012). Many clinical assessments predict fall risk using a variety of gait, balance, and functional tasks that are timed, measured, or scored (Fabre et al., 2010). These clinical assessments provide an overview of strength, balance, power, coordination, and other abilities related to fall risk of a given patient, but the specific impairment(s) that might be responsible for the indicated increase in fall risk are generally determined by clinical judgment and associated follow-up tests. For example, the Timed-Up-and-Go (TUG) test is a popular and effective clinical assessment for fall risk comprising standing from a chair, walking 3 m, turning, returning to the chair, then sitting back down. Patients who take longer than 13.5 s to complete this test are at-risk for falls (Shumway-Cook et al., 1997), but this result could be due to specific impairments of strength, gait, balance, or a combination thereof. These specific impairments can often be visually detected by the clinician and recently instrumented versions of the TUG have been created to better quantify portions of the TUG (Salarian et al., 2010), but these specific impairments are not reflected by the score on the clinical TUG time and more subtle kinetic differences may be more difficult to discern. This knowledge and understanding of patient-specific impairments is critical for clinicians to differentially diagnose patients and customize a clinical treatment plan.

The maximum step length (MSL) test is a rapid clinical assessment that requires dynamic balance and leg strength. To execute this test the arms are folded across the chest and the subject steps out as far as possible while still being able to return to the starting position in a single step (Medell and Alexander, 2000). This test originally included steps to the front, back, and both sides, but as all six MSL steps (three directions with both legs) were found to be highly correlated (Cho et al., 2004; Lindemann et al., 2003), only steps to the front are now usually administered (Lindemann et al., 2008). The MSL is generally performed as a single continuous movement, although a pause is permitted between the out step and return step. Clinically, decreases in MSL correlate with increasing decade of life (Lindemann et al., 2003), performance on

* Corresponding author at: 8900 Grand Oak Circle, Room 149, Tampa FL 33637-1022, USA.
E-mail address: Brian.Schulz@va.gov (B.W. Schulz).

0268-0033/$ – see front matter. Published by Elsevier Ltd
http://dx.doi.org/10.1016/j.clinbiomech.2013.08.002

many clinical assessments known to predict fall risk (Cho et al., 2004), and MSL without a return step of <66% height (or with a return step of <54.4% height as converted using data from Schulz et al., 2007) has been shown to prospectively predict falling with a sensitivity of 70% and a specificity of 69% (Lindemann et al., 2008). Biomechanically, greater MSL has been found to correlate with greater knee and hip extensor speed, strength, and power capacities (Schulz et al., 2007) as well as with greater peak stepping knee and hip kinematics and kinetics during the "pushback" phase (dual support with feet apart — Fig. 1) of the task (Schulz et al., 2008). However, younger subjects also have greater MSL and knee and hip extensor capacities. This multicollinearity complicated the interpretation of these data, as subjects who were capable of stepping further were both stronger and younger. The effects of age and step length could not be separated because these prior studies collected data only for maximum length steps and did not quantify the biomechanical changes across a range of step lengths to fully describe how the kinetics of the MSL test change with step length and age group.

Co-contraction of agonist and antagonist muscles contributes to increased joint stiffness (Manchester et al., 1989) and is used to control joint stability (Benjuya et al., 2004; Kellis, 1998). Increased joint stiffness during high level of co-contraction (agonist/antagonist) may introduce postural instability and impair movement (Horak et al., 1992). In other words, increased co-contraction can result in declining ability to maintain balance during static/dynamic (e.g., standing/stepping) tasks (Horak et al., 1992). During forward stepping, co-contraction of vastus lateralis and medial hamstrings has been used to stabilize motion (Tseng et al., 2007) and older adults have been shown to have greater co-contraction than younger adults (Hsu et al., 2007; Okada et al., 2001). These age-related increases in co-contraction could also play a role in MSL kinetics, but these data have not yet been recorded during the MSL.

To determine the independent effects of step length and age group on hip and knee kinetics and knee co-contraction, healthy younger and older men and women all stepped out-and-back (as in the MSL test) to the same relative target distances while kinematic, kinetic, and electromyographic (EMG) data were recorded. As the MSL biomechanics of fallers have not yet been reported, a cohort of older fallers was also tested to determine if impairments associated with a history of falls result in different biomechanics from unimpaired subjects of similar age. We hypothesized that 1) peak hip and knee kinetics and knee co-contraction would increase for all groups with greater step length, 2) unimpaired older subjects would utilize greater hip and knee kinetics and knee co-contraction to reach the same step lengths as young controls, and 3) older fallers would utilize greater hip and knee kinetics and knee co-contraction to reach the same step lengths as older non-fallers.

2. Methods

2.1. Subjects and instrumentation

A convenience sample of 14 younger (mean (SD) of 27(5) years; age range of 20–35 years) and 14 older (72(5); 66–82) non-fallers, as well as 11 older fallers (75(6); 70–89) were recruited from the community. Half of the non-faller groups and 9/11 of the fallers were men. The non-fallers all had no major health problems, 20/20 corrected vision, and good balance as defined by one-legged stance times of over 30 s on each foot. Exclusion criteria for all subjects were osteoporosis, blood pressure below 90/60 or above 160/90 mm Hg, chronic back pain, impaired cognition (Mini Mental State Exam <24), poor corrected vision (<20/50), and any recent lower extremity injury.

After completing the informed consent process, each subject was fitted with standardized shoes (model 811, New Balance Athletic Shoe, Inc., Boston, MA, USA). A 13-camera Vicon MX40 motion capture system (Vicon, Centennial, CO, USA) was used to record body segment motions at 120 Hz. Ground reaction force data from three AMTI force plates (Advanced Mechanical Technologies, Inc., Watertown, MA, USA) and electromyography (EMG) data from vastus lateralis and medial hamstrings collected by a 16-channel Delsys Bagnoli EMG system (Delsys Inc., Boston, MA, USA) were recorded at 1.8 kHz and synchronized with the motion data using Vicon Workstation 5.2.9.

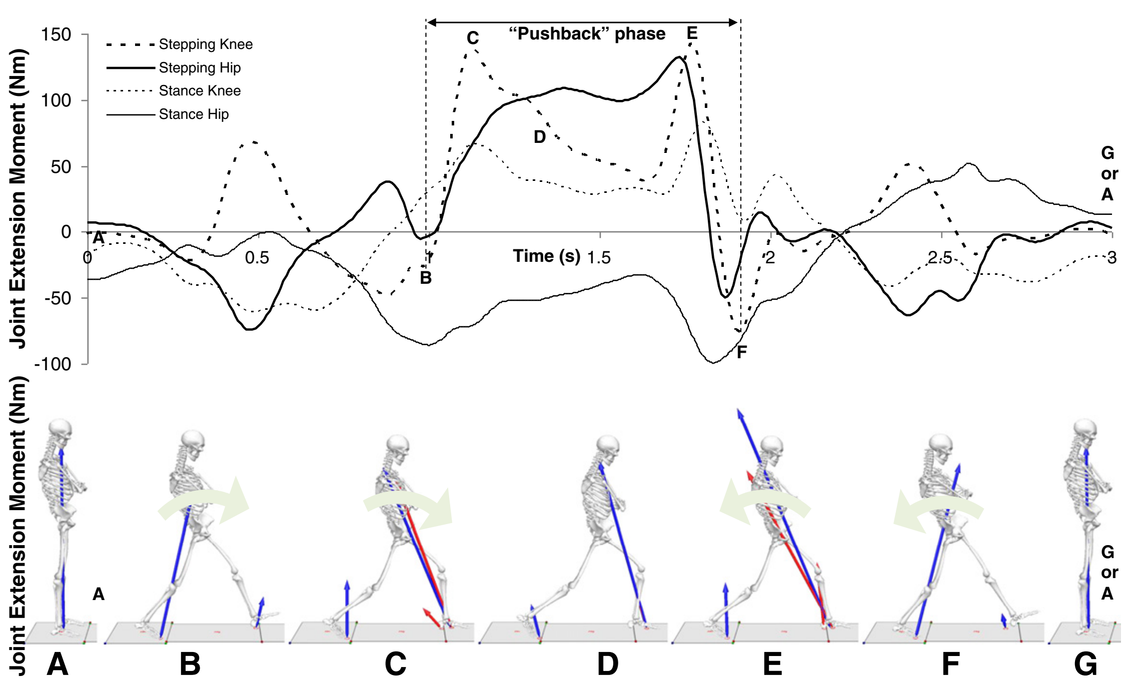

Fig. 1. Example moment data for MSL being performed to target length of 50% height. A and G = starting and ending positions; B = initial contact of stepping foot; C = eccentric knee moment peak; D = point of maximum knee flexion angle and reversal of knee rotation velocity from flexion to extension; E = concentric knee moment peak; F = foot off of return step. General motion of torso indicated by curved block arrows and "pushback" phase examined here indicated by dashed lines. Arrows in bottom panels indicate ground reaction forces on feet; in panels C and E the foot landed across two plates and both the individual and combined forces are displayed.