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Effects of age and step length on joint kinetics during stepping task

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ABSTRACT

Following a balance perturbation, a stepping response is commonly used to regain support, and the distance of the recovery step can vary. To date, no other studies have examined joint kinetics in young and old adults during increasing step distances, when participants are required to bring their rear foot forward. Therefore, the purpose of this study was to examine age-related differences in joint kinetics with increasing step distance. Twenty young and 20 old adults completed the study. Participants completed a step starting from double support, at an initial distance equal to the individual's average step length. The distance was increased by 10% body height until an unsuccessful attempt. A one-way, repeated measures ANOVA was used to determine the effects of age on joint kinetics during the maximum step distance. A two-way, repeated measures, mixed model ANOVA was used to determine the effects of age, step distance, and their interaction on joint kinetics during the first three step distances for all participants. Young adults completed a significantly longer step than old adults. During the maximum step, in general, kinetic measures were greater in the young than in the old. As step distance increased, all but one kinetic measure increased for both young and old adults. This study has shown the ability to discriminate between young and old adults, and could potentially be used in the future to distinguish between fallers and non-fallers.

1. Introduction

Following a balance perturbation, one or more steps are commonly used to regain support. A number of studies have used a forward lean and release protocol to instigate a balance perturbation, simulating a fall (Hsiao-Wecksler and Robinovitch, 2007; Madigan and Lloyd, 2005). Participants lean forward while in a harness and are released with instructions to recover by taking one step, though some studies have focused on comparing multiple steppers to single steppers (Carty et al., 2011, 2012). Instructing participants to limit (or not limit) the number of steps during forward lean recovery was shown to have no effect on lower extremity peak joint torques (Cyr and Smeesters, 2007). Studies show young adults can recover from larger lean angles than old (Madigan and Lloyd, 2005; Thelen et al., 1997; Wojcik et al., 1999). Most of the forward lean and release studies focused on kinematics and kinetics from release to heel contact. One study examined joint kinetics during the support phase of the forward lean protocol, from heel contact to steady state, and found old adults had trends towards larger peak extensor torques at the hip and ankle and significantly lower peak knee extensor torques compared to young adults, indicating different phases of recovery have different joint torque requirements (Madigan and Lloyd, 2005). Additionally, maximum recovery lean magnitude as a percent of body weight and the number of steps to recover from a forward lean at 25% body weight was found to be a predictor of future falls (Carty et al., 2015). These studies provide valuable information, but can also be time consuming and require specialized equipment.

The maximum step length (MSL) test has been used as a clinical assessment of balance (Cho et al., 2004; Nnodim et al., 2006). The MSL test requires a person to step out with one leg as far as possible, and then return to the starting position (Medell and Alexander, 2000). The MSL is shorter in old adults compared to young (Medell and Alexander, 2000; Schulz et al., 2008) and hip and knee kinetics were greater for young women compared to old women during MSL (Schulz et al., 2008). During the forward MSL test (step out and back), peak torques occurred during the "push back" phase (stepping back) (Schulz et al., 2007). This may be one reason the authors explored a variation of the MSL, "back only", where participants started with their feet separated in double support, then returned both feet together by taking a backward step. When participants were instructed to rank the difficulty of the various versions of the MSL, the majority of the participants qualitatively rated the "back only" version of the MSL as the most difficult (Schulz et al., 2007). Both versions of the MSL test require less time to set up than the forward lean protocol as there is no specialized equipment required to place participants into the initial starting position.

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This study explored a movement similar to the MSL "back only" version in that the starting position is also double support. However, in the current study, the participant steps forward, bringing the back foot alongside the front foot, completing the step. As the back stepping movement is less likely during recovery from a fall, the forward stepping movement was examined as a more natural motion after a balance recovery step. This is an important extension to balance-perturbation tests such as the forward lean and release, since adults must also be able to re-initiate forward motion after a balance recovery step(s), and the inability to do so may be another cause of loss of balance. The static starting position isolates a worst-case scenario, when a person does not have momentum to continue forward motion with a second step.

To date, no other studies have compared joint kinetics in young and old adults during increasing step distances, starting in double support and completing the step. Therefore the purpose of this study was twofold: to examine age-related differences in the maximum step distance participants are able to complete, and to examine age-related differences in joint kinetics with increasing step distance. It was hypothesized that (1) young adults are able to successfully complete longer step distances than old adults, (2) peak joint kinetics will increase for both groups as step distance increases, and (3) young adults will have larger peak joint kinetics than old adults during their maximum step distance.

2. Methods

Twenty young (10 male, 10 female) and 20 old (10 male, 10 female), healthy adults were recruited from the local community to complete the study (Table 1). The study was approved by Bucknell University's Institutional Review Board and written consent was obtained.

The study consisted of participants beginning in double support at an initial distance equal to the individual's average step length, and stepping forward with the back foot to bring it alongside the front foot. The distance between the front heel and back heel was increased by 10% of body height (BH) until the participant was unable to complete the step successfully. To determine step length, reflective markers were placed on the right and left heel of the participant. They were then instructed to walk normally in a straight line across the room. After a minimum of three passes, data was recorded using a Vicon Motion Analysis T-10 Series System (Motion Systems Ltd., Centennial, CO, USA). Average step length was calculated from a minimum of three recorded step lengths.

The study began with the participant's dominant foot on the front force plate and non-dominant foot on the back force plate (Fig. 1). Dominance was determined by asking the participants with which foot they would kick a soccer ball. Participants were barefoot and instructed to stand relaxed with arms across their chest and look straight ahead. When signaled, they stepped forward, ending with both feet on the front force plate, with heels on a target line. Three trials were attempted with the dominant leg forward followed by three trials with the non-dominant leg forward. Upon successful completion of two out of the three trials, the step distance was increased. A trial was deemed a failure if participants uncrossed their arms from their chest during the trial, were unable to successfully reach the force plate, or lost their balance while stepping.

Fig. 1. Double support starting position for the study, with one foot on the front force plate and one foot on the back force plate.

Table 1
Participant characteristics by age group and gender. Mean (standard deviation) reported for age, height, and mass.

	Age (yr)	Height (m)	Mass (kg)
Young female (n=10)	20.3 (2.0)	1.64 (0.08)	65.1 (16.7)
Young male (n=10)	19.6 (1.5)	1.80 (0.08)	76.1 (11.5)
Old female (n=10)	73.8 (3.5)	1.60 (0.04)	64.7 (10.4)
Old male (n=10)	77.4 (5.6)	1.74 (0.06)	80.0 (13.0)

Whole body kinematics and ground reaction forces were recorded during all trials. Forty-eight reflective markers were placed bilaterally over selected anatomical landmarks on the head, arms, trunk, and lower extremities (Fig. 1). Marker data was sampled at 100 Hz using the Vicon Motion Analysis T-10 Series System and low-pass filtered using a 4th order zero-phase shift Butterworth filter at 6 Hz. Ground reaction forces were sampled at 1000 Hz using two force plates (AMTI, Watertown, MA, USA) and low-pass filtered using a 4th order zero-phase shift Butterworth filter at 25 Hz.

Lower extremity sagittal plane joint torques were estimated using inverse dynamics at the ankle, knee and hip (Winter, 2005). Segmental masses, center of mass location, and mass moment of inertia were based on existing anthropometric models (de Leva, 1996; Pavol et al., 2002). Custom MATLAB code determined the start and end of the trial. The start of a trial was designated when the vertical ground reaction force on the back force plate exceeded the mean of the vertical components from the beginning of data collection by three standard deviations. To establish the end of the trial, the time at which the derivative of the stepping leg heel and stepping leg toe marker in the anterior–posterior direction was less than zero was determined. The end of the trial was the latter of the two times. Visual confirmation was used to verify the points. Upon preliminary analysis of the data, no differences between the left-foot and right-foot stepping trials were determined; therefore, only right foot stepping trials were analyzed.

Dependent measures included peak joint torques throughout the trial (start to end) for the ankle, knee and hip of both the stepping (back) and stance (front) leg. Additionally, maximum power absorbed and maximum power generated throughout the