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Knee osteoarthritis negatively affects the recovery step following large forward-directed postural perturbations

Mackenzie L. Pater [a,*], Noah J. Rosenblatt [a,1], Mark D. Grabiner [a]

[a] Department of Kinesiology and Nutrition, University of Illinois at Chicago, Chicago, IL 60612, United States

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ABSTRACT

The reasons for higher fall risk of people with osteoarthritis (OA) compared to people without OA are not known. It is possible that following a loss of balance OA may negatively affect the recovery stepping response. Stepping responses have not been reported for people with knee OA. Here, we compared recovery step kinematics following laboratory-induced trip and following a large treadmill-delivered perturbation simulating a trip between a group of women with and without self-reported knee OA. We hypothesized that knee OA would significantly impair recovery step kinematics compared to those of a control group. Following the laboratory-induced trip, step length and trunk flexion velocity at recovery step completion of women with OA were significantly impaired and more so for the women who fell. Following the treadmill-delivered perturbation, the recovery step kinematics of women with OA were not significantly impaired. For both perturbations, the women who fell had significantly impaired recovery step kinematics compared to those who did not fall, regardless of OA. The results are consistent with previous work on healthy middle aged and older women and suggest that the same biomechanical risk factors for trip-related falls are shared by middle age and older women regardless of the presence of knee OA. The results support the need to determine whether training protocols which have been shown to improve recovery step kinematics and reduce prospective falls by healthy older women can have similar outcomes for people with knee OA.

1. Introduction

Falls are generally reported to occur by one out of every three older adults each year (Centers for Disease Control and Prevention, 2015) and are associated with mortality, disability, decreased independence, and early admission to nursing homes (Sterling et al., 2001). Furthermore, in 2013, falls were associated with $34 billion in direct medical care costs (Centers for Disease Control and Prevention, 2015). These significant consequences in combination with the size of the aging population highlight the value of more effective fall prevention interventions. A subpopulation of people at risk for falls are those who have lower extremity osteoarthritis (OA). A growing body of literature suggests that people with lower extremity OA have an approximately 25% greater risk of falls and 20% greater risk of fracture compared to their age-matched counterparts without OA (Prieto-Alhambra et al., 2013). Despite a growing body of literature highlighting an increased fall and injury risk by people with OA, currently, fall-prevention is not a part of standard OA management.

The underlying mechanisms of the increased fall risk are not known. However, many of the risk factors for falls by people with OA overlap with those established for older adults. These broad and general risk factors include strength and gait deficits, balance impairments and pain (Hoops et al., 2012). Thus, OA may not be an independent risk factor for falls. Rather, it is possible that the increased fall risk of people with OA reflects an amplification by the disorder on the aggregate effect of other known risk factors (Hoops et al., 2012).

Trips are the most common cause of falls and account for 39-77% of falls by older adults (Berg et al., 1997; Hill et al., 1999; Overstall et al., 1977). Following a trip, a person will fall if the recovery response, generally in the form of a stepping response, is insufficient to restore dynamic stability. In healthy older adults, a successful stepping response involves limiting trunk flexion and trunk flexion velocity prior to completion of an initial recovery step of sufficient length. These important biomechanical variables have reproducibly discriminated those who fall from those who do not fall following both laboratory-induced trips and treadmill-delivered perturbations

* Correspondence to: University of Illinois at Chicago, Department of Kinesiology and Nutrition, 1919W Taylor St, Room 650 MC 994, Chicago, IL 60612, United States. Tel.: +1 312 413 9432.
E-mail address: mackenzie.pater@gmail.com (M.L. Pater).
[1] Dr. William M. Scholl College of Podiatric Medicine's Center for Lower Extremity Ambulatory Research (CLEAR), Rosalind Franklin University of Medicine and Science, North Chicago, IL 60064, United States.

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simulating trips, (Pavol et al., 2001; Owings et al., 2001). Importantly, these biomechanical variables are amenable to intervention using trip-specific perturbation training (Grabiner et al., 2012), which has been shown to reduce prospectively measured trip-related falls by healthy middle-aged and older women (Rosenblatt et al., 2013).

Biomechanics of the recovery step(s) following laboratory-induced trips or treadmill-delivered perturbations that simulate a trip have not been reported for people with knee OA. Given that a trip-related fall primarily results from an improper stepping response, there is little reason to expect that the presence of OA would alter the relationship between improper stepping responses and the probability of a fall occurring. However, it is plausible that knee OA may be associated with impairments of important recovery step kinematics that could explain increased fall risk. Thus, the purpose of this study was to serve as an initial effort to establish the extent to which knee OA affects important biomechanical variables previously reported to differ between successful and failed recovery responses by healthy middle aged and older adults (e.g. trunk angle and trunk angular velocity at initial recovery step completion and recovery step length). Our primary hypothesis was that knee OA would significantly impair recovery step kinematics following two types of large forward directed perturbations that simulate trips (Grabiner et al., 2012; Owings et al., 2001; Pavol et al., 2001).

2. Methods

2.1. Experimental design

Twenty-five women (60.8 ± 6.9 yrs, 163.8 ± 5.7 cm, 82.6 ± 14.4 kg) who had self-reported physician-diagnosed knee OA (i.e. answered "yes" to the question, "has a doctor/physician ever told you that you have osteoarthritis in your knee(s)?") volunteered to participate in this study. A control group of 25 women (60.4 ± 7.8 yrs, 163.0 ± 6.2 cm, 76.6 ± 18.9 kg) also volunteered to participate in the study. The women in the control group self-reported no prior diagnosis of knee OA and also reported no lower extremity pain in the last year. Women evaluated their current knee pain using a 100 mm visual analog scale (VAS) pain intensity rating, for which 0 referred to "no pain" and 100 to "worse imaginable pain". Women also completed the Knee Injury and Osteoarthritis Outcomes (KOOS) questionnaire. The KOOS questionnaire is a validated patient-report measurement assessing an individual's opinion about their knees and associated problems (Roos et al., 1998). The KOOS questionnaire is composed of 5 subscales. In each subscale, higher scores indicate fewer knee-related problems or symptoms. Women were permitted to take their daily medications prior to their visit. Exclusion factors for all participants included a self-reported inability to walk for 15 min without stopping, having had knee or hip replacement surgery, or having received any pain-relieving injections in the last six months. All procedures were approved by the University of Illinois at Chicago Institutional Review Board and participants provided written informed consent prior to participation.

Women received two types of large, forward-directed, postural perturbations. Both perturbations took place on the same visit to the laboratory. For the first perturbation, a laboratory-induced trip, a mechanical obstacle was manually triggered by an investigator to rise 5 cm from the laboratory floor and obstruct the motion of the swing limb during gait. The women were instructed to walk at a self-selected speed along a 10-meter walkway and were informed that a trip may take place during an upcoming, but unspecified trial. During all trials, a decoy tripping rope was positioned across the gait path and intended to divert the women's attention away from the location at which the trip would occur. Only one attempt was made to trip each participant. The outcome of the trip was documented as a "fall", a "recovery", or a "miss". A fall occurred when a panel of two investigators determined that a woman unambiguously failed to recover dynamic stability and became fully supported by the safety harness (based on a record video of the trial). A recovery was one in which a panel of two investigators determined the woman unambiguously recovered dynamic stability without engaging the safety harness. In the event that the two investigators differed on their interpretation of the fall/recovery, a third investigator was asked to view a video capture of the trial and make a determination. Misses occurred when the mechanical obstacle was triggered at an inappropriate time and a trip did not occur. Misses ($n = 10$) were excluded from subsequent analyses.

The second perturbation was delivered by a microprocessor-controlled, stepper motor-driven, dual-belt treadmill (ActiveStep^{TM}, Simbex, Lebanon, NH). The women stood upright, with arms at their side, feet at a self-selected distance apart, and heels aligned. None of the women in the study had prior experience with large treadmill-delivered postural perturbations. The women were informed that following a verbal signal the treadmill would move "sometime in the next minute" and, when it did so she should "do whatever you can to recover your balance". When activated by the investigator, the treadmill accelerated in the posterior direction to 1.00 m/s in about 170 ms causing the participant to become dynamically unstable and rotate in the forward direction. After achieving their peak velocity the treadmill belts were maintained at 1.00 m/s for 5 s before decelerating to zero m/s in 2 s. The perturbation, which required at least one step to restore dynamic stability (Fig. 1), induced trunk kinematics similar to those following a laboratory-induced trip (Owings et al., 2001). For both perturbations, women wore their own comfortable walking shoes. A safety harness ensured that the woman's hands and knees could not contact the floor/treadmill belt if she were unable to restore dynamic stability. Recoveries were classified as either successful (non-fallers) or not successful (fallers) in the same manner as the laboratory-induced trip (i.e. determination of two investigators, with a third investigator, if needed). A successful recovery was one in which the woman unambiguously recovered dynamic stability without engaging the safety harness.

2.2. Kinematics of the recovery stepping response

During both the laboratory-induced trip and the treadmill-delivered perturbation, the three-dimensional positions of 22 reflective markers placed on the participants were tracked using an 8-camera motion capture system (Motion Analysis Co., Santa Rosa CA) operating at 120 Hz. Although participants may have utilized more than one step in attempt to restore dynamic stability, kinematics associated with the initial (i.e. the first) recovery step were determined. For both perturbations, custom software (MatLab: Mathworks, Cambridge, MA) was used to compute kinematics from the motions of the reflective markers. Kinematics of interest included: trunk flexion angle at (initial) recovery step completion, trunk angular velocity at recovery step completion, and initial recovery step length. Initial recovery step completion was defined as the instant at which either the heel or toe of the recovery foot made contact with the treadmill belt or floor. Trunk angle at recovery step completion was calculated relative to the trunk angle prior to the perturbation. Trunk angular velocity at step completion was computed as the first derivative of the trunk angle time series. A negative value indicated a trunk extension velocity. Step length, expressed as a percentage of body height, was calculated as the sagittal plane distance between the centroids of the recovery and stance foot at the instant of recovery step completion. During the laboratory-induced trip, the recovery strategy was categorized as either lowering or elevating (Pavol et al., 2001). A *lowering strategy* occurred when the tripped limb was immediately lowered to the ground and acted as the support limb while the contralateral foot was used to complete the initial recovery step. An *elevating strategy* occurred when the tripped limb was used as the recovery limb. The walking velocity prior to the instant of the trip was computed as the average rate of horizontal displacement of the sacral marker during the 500ms prior to the swing limb contact with the obstacle.

2.3. Statistics

Analysis of the laboratory-induced trip was conducted using a 2 × 2 *Group* (OA vs. control) X *Fall Outcome* (fall vs. no fall) Analysis of Covariance (ANCOVA). The pre-trip walking velocity and recovery strategy were used as covariates as they have been shown to affect recovery kinematics following laboratory-induced trips (Pavol et al., 1999). Separate ANCOVAs were used for trunk angle at initial recovery step completion, trunk angular velocity at initial recovery step completion and recovery step length. As treadmill-delivered perturbations were initiated from zero velocity, it was not necessary to include pre-trip walking velocity or recovery strategy as covariates. Thus, separate 2 × 2 *Group* (OA vs. control) X *Fall Outcome* (fall vs. no fall) Analyses of Variance (ANOVA) were used for each of the biomechanical variables to test the primary hypothesis.

For each dependent variable, the strongest support for the hypothesis was considered to be the presence of a significant main effect for both *Group* and *Fall Outcome* and the absence of a significant *Group* by *Fall Outcome* interaction such that the values of important recovery step kinematics were impaired in the OA group compared to the control group, independent of the outcome of the perturbation. All statistical analyses were performed using IBM SPSS 22.0 (Armonk, NY) and the significance level was set at 0.05.

3. Results

The women in the OA and control groups were generally well-matched anthropometrically. The between-group differences in age and BMI were not significant ($p > 0.05$, Table 1). Women in the OA group reported a significantly higher level of knee pain as assessed by the VAS compared to the control group (Table 1). Women with knee OA also reported significantly lower (i.e. worse) scores on the KOOS total and each sub-scale compared to the control group (Table 1).