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Perception of symmetry and asymmetry in individuals with anterior cruciate ligament reconstruction

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ABSTRACT

Background: Changes in the quantity, quality and integration of sensory information are thought to persist long after anterior cruciate ligament reconstruction and completion of physical therapy. Our purpose was to investigate the ability of individuals with anterior cruciate ligament reconstruction to perceive imposed asymmetry and symmetry while walking.

Methods: Twenty participants with anterior cruciate ligament reconstruction and 20 controls walked on a split-belt treadmill while we assessed the ability to detect symmetry and asymmetry at fast and slow speeds. Detection scores and spatiotemporal data during asymmetric and symmetric tasks in which the belts were coupled or decoupled over time were recorded.

Findings: The ability to detect symmetry and asymmetry was not altered in individuals with anterior cruciate ligament reconstruction compared to healthy young adults. The belt-speed ratio at detection also correlated to asymmetry for step length, stride length, double support time, and stance time. However, the anterior cruciate ligament reconstruction group appeared to utilize unique information to determine detection. When asked to detect symmetry at a fast speed, no asymmetry scores significantly correlated with belt-speed ratio in the anterior cruciate ligament reconstruction group. Conversely, asymmetry in stride length, step length, and stance time all significantly correlated with belt-speed ratio at detection in the control group.

Interpretation: Specific sensory cues arising from the speed of the leg may also augment perception of symmetry. This strategy may be necessary in order to successfully execute the motor task, and could develop due to altered sensory information from the reconstructed knee at faster walking speeds.

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1. Introduction

Locomotor adaptation paradigms using split-belt treadmills (SBT) have provided important insight into the neural control of movement and the ability of an individual to alter motor behavior of gait. Adaptation is a short-term learning process, which provides information with respect to how much the body can adapt to a new behavior and is considered a surrogate for the amount of flexibility within a behavioral pattern (Bastian, 2008; Reisman et al., 2010). During SBT walking the two belts can be decoupled such that one leg walks faster than the other, resulting in both reactive (fast) and predictive (slow) adjustments adaptation to an asymmetric walking pattern (Reisman et al., 2010). Recently, we have documented that individuals with anterior cruciate ligament reconstruction (ACLR) following anterior cruciate ligament (ACL) injury demonstrate altered locomotor adaptation to decoupled belt speeds (Roper et al., 2016). Specifically, we observed impairments in both slow-adapting and fast-adapting derived gait parameters, suggesting that fundamental features of motor control remain altered despite surgical reconstruction and completion of physical therapy. Because individuals with ACLR demonstrate alterations in locomotor adaptation and also in proprioception (Littmann et al., 2012; Reider et al., 2003), deficits in the ability to accurately perceive asymmetric and symmetric belt leg movements may explain the altered SBT adaptation pattern observed in this population.

Diminished sensation brought on by ACL injury may therefore inaccurately render the representation of the positions of body segments relative to one another (Ivanenko et al., 2011). Sensory receptors are important for successful adaptation to the SBT, and provide critical afferent information concerning both the external and internal environmental conditions of the body and are important for the execution of proper movements. Indeed, a loss of sensory information could affect the ability of an individual with ACL-R to accurately perceive altered or asymmetric movements. This may at least in part explain why people with ACL reconstruction ACLR execute several functional activities with abnormal and asymmetric movements (Gao and Zheng, 2010; Roewer et al., 2011; White et al., 2013). These gait impairments have been shown to persist for up to 17 months after surgery despite surgical reconstruction and successful completion of rehabilitation programs (Bulgheroni et al., 1997; Lewek et al., 2002). Understanding to what extent persons with ACLR are able to detect asymmetric and symmetric

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movements would be important to shed light on locomotor adaptation; and provide therapists with knowledge to develop rehabilitation programs targeting locomotor control deficits.

Previous studies attempting to evaluate changes related to perception following ACLR have presented an incomplete picture of sensory function of the ACLR knee. Both joint position sense (active reproduction of passive positioning) and kinesthesia (the threshold to detect passive motion) have been used in the literature to measure differences in sensory function of the ACL-R knee. When measuring the threshold to detect passive motion, persons with ACL-R display decreased levels of joint motion perception in the reconstructed knee compared to their intact side (Lephart et al., 1992). Yet, during joint position sense testing, persons with ACL-R were better able to actively reproduce knee angles with their reconstructed leg compared to their healthy side six months postoperatively (Reider et al., 2003). The joint position sense task and the threshold for detection of passive motion task can only provide researchers with a limited evaluation of the reconstructed knee and may not accurately detect or represent the functional role of proprioception during locomotion in individuals with ACLR. Additionally, because individuals with ACLR demonstrate alterations in locomotor control, it would seem important to investigate perception of limb movement during a functional locomotor task, which could be beneficial in determining the significance of these sensory changes.

Unfortunately, no study has yet employed a method of measuring perception during a functional locomotor task, which could be beneficial in determining the clinical and neurophysiological significance of these changes in sensorimotor control. Therefore, the aim of this study was to understand the ability of individuals with ACLR to perceive imposed (1) asymmetry and (2) symmetry while walking on a split-belt treadmill (SBT). We hypothesized: 1) the ability to detect symmetry and asymmetry would be altered in individuals with ACLR when the speed of the belt under the reconstructed limb was manipulated compared to when the speed of the belt under the intact limb was manipulated; 2) the ability to detect symmetry and asymmetry would be altered when the reconstructed limb speed was manipulated in individuals with ACLR compared to healthy young adults; and 3) the ability to detect symmetry and asymmetry would be similar when the intact limb speed was manipulated in individuals with ACLR compared to healthy young adults.

2. Methods

2.1. Participants

This study was approved by the University's Institutional Review Board, and informed consent was obtained from each individual prior to their participation. Twenty participants with ACLR (12 female, 8 male, age: 20(1) yrs, height 1.71(0.11) m; mass 69(14) kg, 8 autograft hamstring, 7 patellar tendon, 4 Achilles allograft, 1 hybrid allograft/autograft) and 20 healthy age and gender matched controls (HYA) (12 female, 8 male, age: 20(1) yrs, height 1.70(0.12) m; mass 67(14) kg) were recruited. Both groups reported 6(3) h of physical activity per week. None of the participants had walked on a SBT prior to participation in this study. The controls were free from any history of neurological impairment. The ACLR volunteers were able to walk unassisted for a total of 60 min (with optional rest periods) and had sustained at least one anterior cruciate ligament tear verified by examination of a doctor, followed with surgical reconstruction. Only one participant had undergone a second ACLR to the same limb as the first. The time since surgery, type of graft, duration of therapy and current activity level were recorded.

2.2. Experimental protocol

Passive reflective markers were attached to the ankle of each limb. Kinematic data, time-synchronized to the kinetic data, were collected using an 8-camera motion capture system (120 Hz; Vicon, Oxford, UK). Kinetic data were collected as the participants walked on an instrumented SBT (1200 Hz; Bertec Corporation, Columbus, OH). Participants wore noise-cancelling headphones and dribble glasses to limit visual and auditory feedback provided by the acceleration and deceleration of the belts, and were instructed to hold on to the handrails. Following a five-minute warm-up and acclimation to the slow (0.75 m/s) and fast speed (1.5 m/s), participants were asked to “indicate when they perceived a difference or similarity in leg movement” during walking conditions in which one belt speed changed incrementally every three strides (velocity = 0.03 m/s, acceleration = 0.1 m/s^2). Participants indicated a perceived difference or similarity in leg speeds by raising their hand. For symmetry detection and asymmetry detection only one belt speed was manipulated at a time, so the change in speed occurred during the swing phase of every third stride of the leg on the belt being manipulated. Upon indication of perceived difference or similarity by the participant, both belts were adjusted such that they both moved at 1.0 m/s in order to undo the effects of the most-recent walking condition and establish a washout period lasting one minute. After completing the washout period, the next sub-condition was performed until all sub-conditions were completed. The three conditions performed are defined below.

2.2.1. Symmetry detection

This condition allowed a representative measure of the participant's acuity in detecting symmetry when a walking trial began asymmetric and rapidly became more symmetric. Participants began walking with one leg moving at the fast speed, and the other at the slow speed. The following sub-conditions occurred in a random order:

1-a) the left leg starts moving at the fast speed and was decreased.

1-b) the left leg starts moving at the slow speed and was increased.

1-c) the right leg starts moving at the fast speed and was decreased.

1-d) the right leg starts moving at the slow speed and was increased.

2.2.2. Asymmetry detection

The purpose of this condition was to observe the participant's sensitivity in detecting when symmetry was no longer present between their leg movements when a walking trial began symmetric and rapidly became more asymmetric. Participants walked on the treadmill with both belts moving together at either the slow speed or fast speed. This condition was repeated three times so that the participant completed the following sub-conditions:

2-a) right leg continues moving at fast speed, left leg gradually decreases.

2-b) left leg continues moving at fast speed, right leg gradually decreases.

2-c) right leg continues moving at slow speed, left leg gradually increases.

2-d) left leg continues moving at slow speed, right leg gradually increases.

2.3. Data processing

All variables calculated for the leg on the fast belt are henceforth referred to as the “fast” leg, and the leg on the slow belt will be referred to as the “slow” leg. Initial contact (heel-strikes) and toe-offs were labeled in Vicon software and were determined using marker velocity profiles and a 50-N force-plate threshold (Neckel et al., 2008). Marker data were filtered using a 4th-order low-pass Butterworth filter with a cutoff frequency of 10 Hz. The speed of each belt was also recorded throughout each condition.