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Reliability of the knee muscle co-contraction index during gait in young adults with and without knee injury history

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ABSTRACT

Despite the frequent use of the electromyography-based muscle co-contraction index (CCI) to examine muscular control of the knee joint in young adults with and without knee injury history, the reliability of the CCI in this population is unknown. The purpose of this study was to quantify within-day and between-day reliability of the knee muscle CCI during gait in young adults with and without knee injury history. Twenty young adults (10 males, 10 females) with and without history of intra-articular knee injury performed repeated gait analyses on two different days. Surface electromyography of periarticular knee muscles was performed to determine CCIs for medial and lateral knee extensor – flexor pairs. Absolute (Bland-Altman ratio limits of agreement) and relative (ICCs) reliability were determined between two sessions on the same day as well as on different days. Within-day reliability was good to excellent for most analyzed co-contraction outcomes (ICCs > 0.9) and was deemed acceptable in the context of clinically relevant changes in co-contraction in response to interventions. Between two separate days, the CCI showed poor reliability with measurement errors of up to 300% and was consequently not recommended as a tool to monitor long-term changes or group differences in knee muscular control.

1. Introduction

The simultaneous activation of antagonistic muscles is often referred to as muscle co-contraction and is frequently studied as a compensation mechanism for joint instability in young adults who have sustained a previous knee injury (Hall et al., 2015; Rudolph et al., 2000, 2001; Tsai et al., 2012). All of the above studies use surface electromyography (EMG) to evaluate the activity of selected muscles of the lower leg during gait and infer muscle co-contraction strategies. One commonly used measure of muscle co-contraction in clinical biomechanics research is the muscle co-contraction index (CCI) (Rudolph et al., 2000). The CCI represents a weighted ratio of the EMG signal intensities obtained from two antagonistic or synergistic muscles with reference to the maximum EMG signal intensity achieved during maximum voluntary muscle contractions (MVCs). This ratio is typically determined for knee extensor – flexor or medial – lateral muscle pairs and then compared between post-knee injury and control groups (Hall et al., 2015; Hurd and Snyder-Mackler, 2007; Sturnieks et al., 2011). In other studies, changes in the CCI are investigated that occur in response to interventions such as knee bracing or perturbation training (Chmielewski et al., 2005; Ramsey et al., 2007).

Conclusions from such investigations to inform clinical practices can only be drawn if the reliability of the CCI for repeated measurements in the population of interest is established. To the best knowledge of the authors, the reliability of the CCI during gait in young post-knee injury and control populations is currently unknown. Previous investigators have reported substantial random error of greater than 200% and poor typical errors of measurements of up to 25% when repeatedly measuring the amplitude of surface EMG signals normalized to MVCs (Ball and Scurr, 2010; Murley et al., 2010). Therefore, one may speculate that the CCI, which relies on such amplitude measurements, would also demonstrate large random error and consequently exhibit low test-retest reliability. Only one study was identified that evaluated the relative reliability of CCIs in a moderate knee OA population (Hubley-Kozey et al., 2013) using the intra-class correlation coefficient. However, these findings may not be generalized to the younger, more active, and less symptomatic populations that are often examined in post-knee injury studies (Whittaker et al., 2015). Furthermore, previous

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pathologies may influence the reliability of biomechanical outcomes in gait analyses (McGinley et al., 2009; Steinwender et al., 2000). Therefore, reliability studies should include individuals with and without the pathology of interest, in this case a previous knee injury, and the pathology group should reflect a continuum of severity from mild to severe (Lijmer et al., 1999; McGinley et al., 2009).

The primary objective of this study was to quantify the absolute and relative intra-rater reliability (within the same day and between two days measured 7–13 days apart) of the knee muscle co-contraction index during gait in young adults with varying knee injury history. A secondary objective was to explore if differences in intra-rater reliability exist between individuals with and without a previous knee injury.

2. Methods

2.1. Study design

This is a reliability study that was conducted in the context of a larger longitudinal cohort study with the goal to investigate outcomes associated with early post-traumatic osteoarthritis 3–10 years following knee joint injury in youth (Whittaker et al., 2017, 2015). For this specific cohort study and for researchers investigating similar longitudinal designs, it is essential to determine the reliability of outcome measures such as the muscle co-contraction index. The description of this study complies with the guidelines for reporting reliability and agreement studies proposed by Kottner et al. (2011).

2.2. Participants

A convenience sampling method was used to recruit twenty young adults (ages 16–31; 10 males, 10 females) who volunteered and provided written informed consent to participate in this study; ten had sustained a previous knee injury (5 males, 5 females) and ten controls had no history of knee injury. The sample size of n = 20 was selected based on feasibility while exceeding the sample size of most previous studies investigating the within or between-day reliability of EMG signal amplitudes (see Burden (2010) for a comprehensive review). Inclusion and exclusion criteria and the knee injury definition were selected to closely resemble the participant characteristics of the Pre-OA cohort study. Specifically, previously injured participants had to (1) be between 18 and 30 years old, (2) have sustained the primary knee injury two to ten years prior to the study, and (3) have not sustained a secondary or contralateral knee injury since then. A knee injury was defined as a self-reported injury to the cruciate or collateral ligaments and/or an injury to the menisci that resulted in both medical consultation as well as disruption of sport participation (Whittaker et al., 2015). Control participants had to be between 18 and 30 years old and exclusion criteria were (1) a history of previous knee injury as defined above or (2) the presence of any other lower extremity injury within six months prior to study participation. Ethical approval for research involving human participants was obtained from the University of Calgary's Conjoint Health Research Ethics Board (Ethics ID E-25075).

2.3. Reliability protocol

Participants visited the Human Performance Laboratory at the University of Calgary on two separate days, about a week (median (range), 7 (7 −1 3) days) apart. The time of day when the testing sessions were performed was kept constant for both visits. During the first visit, participants completed one round of isometric dynamometry followed by two rounds of the same gait protocol. These two rounds of gait testing were separated by about 30 min and were used to determine within-day reliability. During the second visit, participants completed one round of isometric dynamometry and one round of gait measurements. The first rounds from each testing day were used to determine between-day reliability. On both days, all electromyography procedures were carried out by the same investigator (MM, doctoral student, four years of training and experience in electromyography and motion analysis). Motion analysis procedures were performed by two investigators (MM; KL, graduate student, three years of training and experience in motion analysis) according to internally standardized marker placement protocols and participant instructions.

2.4. Data collection

All procedures and assessments were carried out on the side of the previous knee injury in the injury group and on the right side (preferred leg to kick a soccer ball for all participants) in the control group. Upon arrival, participants first filled out an initial questionnaire related to their demographics, injury history, and knee-related function as assessed through the Knee Injury and Osteoarthritis Outcome (KOOS) questionnaire (Roos et al., 1998). Afterwards, participants were prepared for EMG measurements according to widely used SENIAM guidelines including skin preparation (shaving, light abrasion, and cleaning with alcohol wipes) and identification of standardized landmarks for the measurement of surface EMG signals from lower extremity muscles (Hermens et al., 1999). Bipolar surface electrodes (Ag/AgCl, 10 mm diameter, 20 mm inter-electrode distance, Norotrode Myotronics-Noromed Inc., US) were placed in the muscle fibre direction on six lower extremity muscles: vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), medial hamstrings (MH, semitendinosus/semimembranosus), gastrocnemius medialis (GM), and gastrocnemius lateralis (GL). In order to validate the placement of each electrode, manual muscle testing for knee extension and flexion and ankle plantarflexion were performed. EMG signals were recorded with reference to a ground electrode on the tibial tuberosity at 2400 Hz, pre-amplified and bandpass-filtered between 10 and 500 Hz (Biovision, Wehrheim, Germany) via a 12-bit A/D converter (National Instruments, Austin, TX). In addition to EMG recordings, a 1D-accelerometer was taped to the lateral aspect of the heel for heel strike detection during walking trials.

Following the EMG set-up, participants completed a series of standardized submaximal warm-up contractions followed by two trials of five second isometric maximum voluntary contractions (MVCs) for each muscle group (knee extensors and flexors, and ankle plantarflexors). All contractions were completed while seated in a Biodex 3 System Pro (Biodex Medical System Inc, New York, NY, USA) according to the MVC protocol described by Albertus-Kajee et al. (2011). The investigator gave verbal encouragement during all maximum effort trials. The subject's position in the dynamometer was documented on day 1 and kept consistent on day 2.

Prior to the gait measurements, participants were equipped with retroreflective markers that were mounted on the thigh and shank segments to track three-dimensional lower limb kinematics (Fig. 1). In addition, initial static recordings of the participants in an upright standing position were obtained after mounting additional markers over the greater trochanter, medial and lateral knee and ankle joints to define joint center locations. Next, participants completed seven successful trials of barefoot over-ground walking at their preferred speed along a 20 m walkway. The preferred speed was self-selected by the participants while walking on a treadmill before performing the over-ground walking trials. A minimum of six walking trials and a self-selected speed has been recommended to obtain reliable electromyographic data during gait (Kadaba et al., 1985; Shiavi et al., 1998). During each over-ground walking trial, lower-extremity EMG as well as kinematics and synchronized ground reaction forces were recorded for one gait cycle using a high-speed motion analysis system (8 cameras; Motion Analysis Corp, Santa Rosa, CA, USA) and a floor-embedded force plate at sampling rates of 240 Hz and 2400 Hz, respectively. Over-ground walking speed was monitored in real-time using photoelectric timing gates and trials were repeated if the walking speed fell outside of