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Effect of limb dominance and sex on neuromuscular activation patterns in athletes under 12 performing unanticipated side-cuts

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ABSTRACT

Non-contact ACL injuries are one of the most common injuries to the knee joint among adolescent/collegiate athletes, with sex and limb dominance being identified as risk factors. In children under 12 years of age (U12), these injuries occur less often and there is no sex-bias present. This study set out to explore if sex and/or limb dominance differences exist in neuromuscular activations in U12 athletes. Thirty-four U12 males and females had six bilateral muscles analyzed during unanticipated side-cuts. Principal component analysis was performed, capturing differences in overall magnitudes and timing of peak magnitudes. Two-way mixed-model ANOVAs determined significant limb effects with both sexes displaying (i) greater magnitudes in the lateral gastrocnemius and both hamstrings in the dominant limb and (ii) earlier timing of peak magnitudes in both gastrocnemii, both hamstrings and vastus medialis in the non-dominant limb, while no sex differences were identified. This study demonstrated that limb dominance, not sex, affects neuromuscular activation strategies in U12 athletes during unanticipated side-cuts. When developing injury prevention programs for younger athletes, an increased focus on balancing neuromuscular activations in both limbs could be beneficial in reducing the likelihood of ACL injuries in these athletes as they mature through puberty.

1. Introduction

Anterior cruciate ligament (ACL) injures are one of the most common injuries to the knee joint. Reported ACL injuries among collegiate athletes in the United States rose from 86,687 in 1994 to 129,836 in 2006, with rates continuing to rise among these active individuals (Agel et al., 2016). These injuries can be devastating to both an athlete's career and overall quality of life (Button et al., 2008, 2014). ACL injuries generally require an invasive surgery and rehabilitation, and also lead to an increased likelihood of early onset knee osteoarthritis (Hewett et al., 2015; McLean et al., 2004; Simon et al., 2015; Whittaker et al., 2015). Each injury results in the medical cost of approximately $17,000 (USD), with total estimates reaching $3 billion (USD) annually in the United States (Petushek et al., 2015), thereby putting a considerable toll on the patient and the medical system as a whole.

It has been established that adolescent/adult females are three to nine times more likely to sustain a non-contact ACL injury compared to males (Agel et al., 2005; Griffin et al., 2000; Hewett et al., 1999). As such, differences between sexes in neuromuscular activity in the lower extremity have been extensively reviewed, with common findings being; greater ratios of quadriceps (vastus lateralis and vastus medialis) to hamstring activity (biceps femoris and semitendinosus/semimembranosus) (Beaulieu et al., 2009; Hanson et al., 2008; Landry et al., 2007; McLean et al., 2004; Sigward and Powers, 2006) and earlier peak activations (Hanson et al., 2008; Landry et al., 2009) among females. An imbalance in muscle activations can lead to increased anterior tibial translation, which may result in increased strain on the ACL (Grood et al., 1984). Furthermore, the effect of limb dominance on neuromuscular activity has been suggested to be sex-dependent in non-contact ACL injuries. Females (ages 14–38 years) who had sustained a non-contact ACL injury more frequently injured the ACL in their non-dominant limb (67.7%), while males injured the ACL in their dominant limb (74.1%) (Boden et al., 2000). Suggesting that neuromuscular asymmetries between lower limbs should be further investigated as a risk factor for ACL injuries (Negrete et al., 2007). Moreover, different muscle activation patterns have been observed between limbs during unanticipated tasks (Brown et al.,

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2009; Pappas et al., 2015), an important consideration to create a game-like scenario in the laboratory.

As discussed, females are at greater risk of ACL injury compared to males, however this is not the case for all age groups. These injuries are relatively rarely seen in younger cohorts (under the age of 12 years – U12), and there is interestingly no reported sex difference in ACL injury rates until after this age (Shea et al., 2004; Werner et al., 2015). That being said, insurance data from youth soccer athletes shows that ACL injury rates have begun to rise in paediatric populations (including 12 years and younger) (Shea et al., 2004), introducing the debate of proper management of ACL injuries in skeletally immature patients (Gausden et al., 2015; Mall and Paletta, 2013). When a paediatric ACL rupture is diagnosed, there are two possible outcomes: (i) a non-operative approach that may result in long-term meniscal and articular cartilage damage (Guenther et al., 2014; Lohmander et al., 2007) or (ii) a surgical procedure that may cause physis and growth disturbances (Kocher et al., 2002; Woods and O'Connor, 2004). These potential long-term complications can alter the neuromuscular control of the knee joint (Alkjaer et al., 2003) and cause a negative cascading effect on activity levels for these young athletes (McCarroll et al., 1988) and overall knee joint health (Mall and Paletta, 2013). Therefore it is imperative to fully understand the neuromuscular parameters of healthy U12 males and females, before the sex-bias in ACL injury rates appears, especially during dynamic tasks that put these athletes at risk of injury. The knowledge gained will be instrumental in determining how injury prevention interventions should be implemented to improve neuromuscular control in U12 soccer athletes.

There are currently no studies that evaluate sex and limb dominance differences in neuromuscular activation patterns in healthy children (*i.e.* prior to the onset of puberty) during an unanticipated side-cut task. Therefore the purpose of this study was to explore if sex and/or limb dominance-related differences in neuromuscular activation of the knee joint exist in a population of U12 soccer athletes, before the sex-bias presents itself. Before puberty, males and females have yet to begin growth spurts. Anatomical structures of the lower limb and hormonal compositions are reported to be similar (Rogol et al., 2000), thus sex-dependent anatomical risk factors that are often associated with ACL injuries (Boden et al., 2000; LaBella et al., 2014) were deemed negligible on neuromuscular control for this young population. As such, it was hypothesized that there would be no differences in the neuromuscular control patterns between sexes in U12 soccer athletes. The exposure to sport for both males and females of this age group is also quite similar, as competitive teams are only beginning to be introduced. Consequently, neuromuscular activation patterns may not be fully established for each limb and therefore we hypothesized similar neuromuscular strategies between limbs would be observed during side-cuts.

2. Methods

2.1. Participants

Thirty-four U12 soccer athletes (males: n = 17, females: n = 17) were randomly recruited from the Valley District Soccer Association, Nova Scotia, Canada, to participate in this study. Inclusion criteria consisted of participants having no history of significant lower limb injuries, to be injury free at the time of testing, and to be under the age of 12 years. This study received approval from Acadia University's Research Ethics Board (REB 13-33) prior to testing. All participants and a guardian were required to read and sign a consent form. The dominant limb of each participant was distinguished by which limb the participant used to kick a soccer ball for maximal distance.

2.2. Setup

Testing took place within The John MacIntyre motion Laboratory of Applied Biomechanics (mLAB) and outside on the Acadia Athletic Complex's artificial turf field. Anthropometric data were recorded, followed by placement of bipolar surface electrodes from a wireless electromyography (EMG) system (Trigno-16, Delsys Inc., Boston, USA) on the bellies of the semitendinosus/semimembranosus (medial hamstring – MH), biceps femoris (lateral hamstring - LH), medial (MG) and lateral gastrocnemii (LG), and the vastus medialis (VM) and lateralis (VL) of each limb, according to SENIAM guidelines (Hermens et al., 2000) to prevent cross-talk. Raw EMG signals were recorded at 2000 Hz, had preamplifier gains of 1000 times, a bandwidth of 20–450 Hz, a CMRR of −92 dB and input impedance greater than 10^{15} Ω.

Four footswitch pressure sensors (Delsys Inc., Boston, USA) were placed on the insole of each of the participant's soccer cleats, enabling identification of ground contact time. The footswitch pressure sensors were aligned with the distal phalanx of hallux, head of 1st metatarsal, base of calcaneus, and head of 5th metatarsal.

2.3. Procedure

A bias trial was first collected to measure quiet EMG noise, where the participant lay supine, motionless, and relaxed, for two seconds. Next, maximal voluntary isometric contractions (MVICs) were performed on both limbs and included; (i) knee extension and (ii) knee flexion with 45° knee flexion while sitting upright, (iii) plantar-flexion and (iv) dorsi-flexion with ankle in neutral position and knee near full extension, while sitting upright, (v) a standing calf raise, for each leg, with applied resistance on the shoulders and (vi) knee flexion with knee flexed at 55°, while laying prone. Each exercise was repeated twice and held for five seconds, with at least 1-min rest between trials.

Four timing gates (Smartspeed Pro, Fusion Sport, Sumner Park, AUS), each having a light source to enable control of the cutting direction, were arranged in a "Y-formation" on the artificial turf field (Fig. 1). Participants performed a light jogging warm-up, followed by two sprint trials, to determine a mean maximum velocity. Sprint trials began 10 m from the first timing gate. To maintain consistent control for each unanticipated side-cut trial, 75% ± 10% of the mean maximum velocity was used as a target range for their approach velocity. Maximum velocities were also used to determine how much distance timing gates one and two

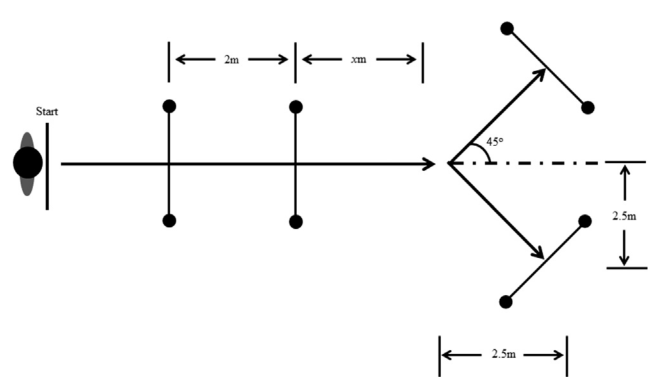

Fig. 1. Timing gate set-up for unanticipated side-cuts. The distance 'x' was adjusted for each participant, accounting for their approach velocity to allow for 0.5 s of reaction time.