Journal of Electromyography and Kinesiology 24 (2014) 98–103

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

The effects of isometric and isotonic training on hamstring stiffness and anterior cruciate ligament loading mechanisms

J. Troy Blackburn [a,*], Marc F. Norcross [b]

[a] Neuromuscular Research Laboratory, University of North Carolina, Chapel Hill, NC, USA
[b] Department of Nutrition and Exercise Sciences, Oregon State University, Corvallis, OR, USA

ARTICLE INFO

Article history:
Received 17 May 2013
Accepted 18 October 2013

Keywords:
ACL
Neuromuscular
Neuromechanics
Viscoelastic
Muscle

ABSTRACT

Greater hamstring musculotendinous stiffness is associated with lesser ACL loading mechanisms. Stiffness is enhanced via training, but previous investigations evaluated tendon rather than musculotendinous stiffness, and none involved the hamstrings. We evaluated the effects of isometric and isotonic training on hamstring stiffness and ACL loading mechanisms. Thirty-six healthy volunteers were randomly assigned to isometric, isotonic, and control groups. Isometric and isotonic groups completed 6 weeks of training designed to enhance hamstring stiffness. Stiffness, anterior tibial translation, and landing biomechanics were measured prior to and following the interventions. Hamstring stiffness increased significantly with isometric training (15.7%; $p = 0.006$), but not in the isotonic (13.5%; $p = 0.089$) or control (0.4%; $p = 0.942$) groups. ACL loading mechanisms changed in manners consistent with lesser loading, but these changes were not statistically significant. These findings suggest that isometric training may be an important addition to ACL injury prevention programs. The lack of significant changes in ACL loading mechanisms and effects of isotonic training were likely due to the small sample sizes per group and limited intervention duration. Future research using larger sample sizes and longer interventions is necessary to determine the effects of enhancing hamstring stiffness on ACL loading and injury risk.

1. Introduction

Neuromuscular training programs have demonstrated modest efficacy in reducing anterior cruciate ligament (ACL) injury risk (Gilchrist et al., 2008; Hewett et al., 2006; Mandelbaum et al., 2005; Yoo et al., 2010). However, these programs incorporate numerous components, and there is little-to-no evidence regarding which components are effective or even necessary (Hewett et al., 2006; Yoo et al., 2010). This large number of components requires a substantial time commitment which may lead to poor compliance. As compliance is paramount for success, future ACL injury prevention programs should be streamlined to minimize the time requirement, thus maximizing efficiency, compliance, and efficacy.

The components included in ACL injury prevention programs should be selected based on evidence identifying (1) characteristics that influence ACL loading, (2) which of these characteristics are modifiable, and (3) the effects of modifying these characteristics on ACL injury risk. ACL-deficient individuals with greater hamstring musculotendinous stiffness (MTS) possess greater functional ability than those with more compliant hamstrings (McNair et al., 1992). Healthy individuals with greater hamstring MTS display less anterior tibial translation during controlled perturbations compared to those with more compliant hamstrings (Blackburn et al., 2011). Greater hamstring MTS is also associated with more favorable landing biomechanics in terms of ACL loading as evidenced by smaller anterior tibial shear forces and frontal plane knee moments, and greater knee flexion at the instants of peak kinetic ACL loading mechanisms (Blackburn et al., 2013). Furthermore, peak frontal plane knee moments predict ACL injury risk prospectively (Hewett et al., 2005), suggesting that greater hamstring MTS may be associated with lesser injury risk. MTS can be enhanced via training, thus modifying this single neuromuscular characteristic may reduce ACL loading and injury risk.

Increases in stiffness have been demonstrated with a variety of training modes (Burgess et al., 2007; Grosset et al., 2009; Kubo et al., 2000a,b; 2001a, 2001b, 2007, 2006, 2009; Pousson et al., 1990), with isometric and isotonic training producing the largest increases. However, all but two of these investigations measured tendon stiffness rather than that of the musculotendinous unit as a whole (i.e. MTS), and none involved the hamstrings, thus it is unclear if these training mechanisms would have the same effects on hamstring MTS. As greater hamstring MTS is associated with

* Corresponding author. Address: The University of North Carolina at Chapel Hill, 124 Fetzer Hall, CB # 8700, Chapel Hill, NC 27599-8700, USA. Tel.: +1 (919) 843 2021; fax: +1 919 962 0489.
E-mail address: troyb@email.unc.edu (J.T. Blackburn).

1050-6411/$ - see front matter
http://dx.doi.org/10.1016/j.jelekin.2013.10.010

lesser ACL loading mechanisms (Blackburn et al., 2013; 2011), demonstrating the ability to enhance this neuromuscular characteristic may inform the development of ACL injury prevention programs. Therefore, the primary purpose of this investigation was to evaluate the effects of isometric and isotonic training on hamstring MTS. A secondary purpose was to determine if increasing hamstring MTS alters ACL loading mechanisms consistent with reduced injury risk.

2. Methods

This investigation utilized a single-blind randomized controlled experimental design. Thirty-six healthy volunteers (18 males, 18 females) were assigned to isometric (IsoM; $n = 12$), isotonic (IsoT; $n = 12$), or control (CON; $n = 12$) groups in a stratified random manner (i.e. equal sex distribution). Subjects had no history of ACL injury, neurological disorder, or lower extremity surgery or injury within the 6 months prior to participation, and completed at least 20 min of physical activity 3× per week. IsoM and IsoT groups completed 6 weeks of training designed to enhance hamstring MTS, while the CON group continued their normal physical activity habits throughout the intervention. The principal investigator was blinded to group assignment. Hamstring MTS, anterior tibial translation, and landing biomechanics were assessed within 1 week prior to and following the interventions. Hamstring MTS does not differ between limbs in healthy individuals (Jennings and Seedhom, 1998), thus all data were sampled from the right leg only. All subjects read and signed an informed consent document which was approved by the university's institutional review board.

2.1. Procedures

Hamstring MTS was assessed via the damped oscillatory technique (Blackburn et al., 2013; 2011; Granata et al., 2002; McNair et al., 1992). Subjects were positioned prone with the hip and knee in 30° of flexion and the foot secured to a load cell (Honeywell Sensotec model 41, Columbus, OH, USA) which permitted measurement of hamstring force (Fig. 1). EMG electrodes (DelSys Inc. Bagnoli-8, Boston, MA, USA) were positioned over the biceps femoris long head to evaluate hamstring activity. Subjects performed a 5s maximal voluntary isometric contraction (MVIC) during which load cell and hamstring EMG data were sampled. The foot was then freed from the loading device, permitting knee flexion/extension, and a load equal to 45%MVIC was secured to the shank (Fig. 2). The investigator then aligned the shank with the horizontal, and the subject contracted the hamstrings isometrically to maintain this position (i.e. 30° of knee flexion). The investigator then applied a downward manual perturbation to the calcaneous, extending the knee and initiating oscillatory flexion/extension. The force used to produce this perturbation is manual, and is, therefore, not controlled experimentally. However, MTS demonstrated excellent intra-session reliability and precision for all subjects at pre-test ($ICC_{2,1} = 0.82$; SEM = 2.90 N/m kg^{-1}) and excellent inter-session reliability across the intervention in the control group ($ICC_{2,k} = 0.87$; SEM = 1.69 N/m kg^{-1}), and previous research (Blackburn et al., 2011) indicates that MTS is independent of perturbation magnitude.

The damped oscillatory knee flexion/extension motion was characterized in the tangential acceleration of the shank segment captured by an accelerometer (PCB Piezotronics model 356A32, Depew, NY, USA) fixed to a splint secured near the ankle. The period between the first two oscillatory peaks in the acceleration was used to calculate the damped oscillatory frequency (Fig. 3), which was then used to calculate MTS via the equation $\boldsymbol{MTS} = \mathbf{4^2} \boldsymbol{mf^2}$, where $\boldsymbol{m}$ is the system mass (shank and foot segment (Dempster et al., 1959) + 45%MVIC) and $\boldsymbol{f}$ is the damped oscillatory frequency. Five trials were averaged for analysis and normalized to subject mass (Blackburn et al., 2009; Granata et al., 2002).

An electromagnetic motion capture system (Ascension Technology Corp. miniBIRDS, Burlington, VT, USA) was used to sample knee kinematics during a double-leg landing from a 30 cm height positioned 50% of subject height from two force plates (Bertec Corp. model 4060, Columbus, OH, USA) from which ground reaction forces and moments were sampled. Sensors were placed on the pelvis, thigh, and shank segments, and a segment-linkage model was created by digitizing the medial and lateral malleoli and

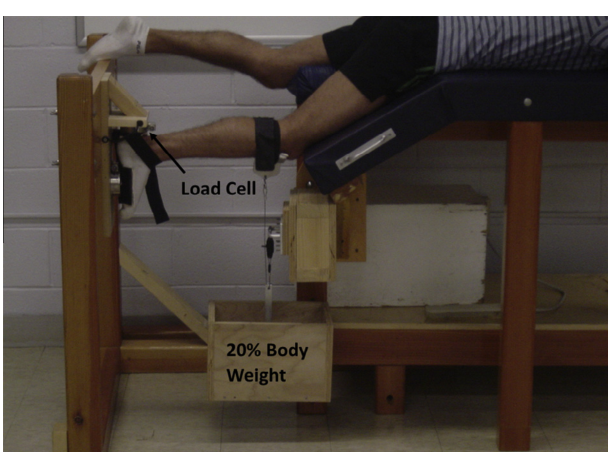

Fig. 1. Subject positioning for MVIC and ATT assessments.

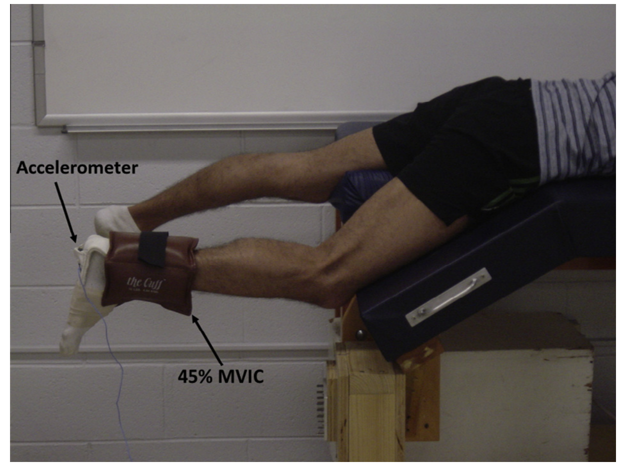

Fig. 2. Subject positioning for hamstring MTS assessments.

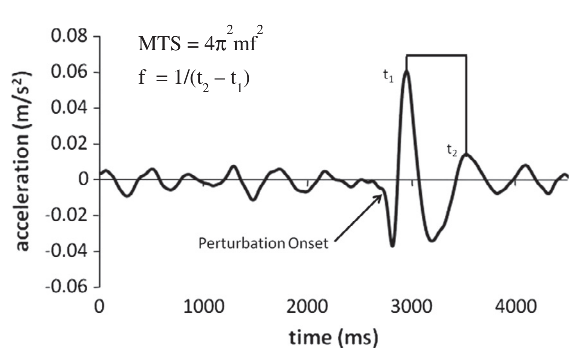

Fig. 3. Damped oscillatory shank acceleration during hamstring MTS assessment. Stiffness was calculated via the equation $\boldsymbol{MTS} = \mathbf{4^2} \boldsymbol{mf^2}$, where $\boldsymbol{k}$ is stiffness, $\boldsymbol{m}$ is the system mass, and $\boldsymbol{f}$ is the damped frequency of oscillation.