THE INFLUENCE OF MUSCULAR ACTIVATION PROFILES ON LOWER LIMB BIOMECHANICS DURING A SPORT-SPECIFIC LANDING TASK

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The purpose of this study was to identify the muscular activation profiles utilised by female athletes during a sport-specific landing task, and examine the effects of varying profiles on biomechanical anterior cruciate ligament (ACL) injury risk factors. Muscular activation profiles were identified from electromyography data using a combination of principal component and cluster analysis methods, with the neuromuscular and biomechanical characteristics of profiles compared. Various muscular activation characteristics contributed to the presence of lower limb biomechanical patterns consistent with ACL injury risk factors. Reduction of ACL injury risk may be achieved by targeting these muscular activation characteristics via neuromuscular training programs.

KEY WORDS: neuromuscular control, kinematics, kinetics, anterior cruciate ligament.

INTRODUCTION: Noncontact anterior cruciate ligament (ACL) injuries often occur during tasks that athletes have replicated in a safe manner countless times (Hashemi et al., 2007). Given the neuromuscular system’s role in controlling lower limb motion (Griffin et al., 2000), it is possible that specific muscular activation profiles contribute to this phenomenon, rendering athletes at-risk of injury. The identification of neuromuscular risk factors provides a basis for the design of targeted interventions (Hewett, Myer, Ford, Paterno, & Quatman, 2012). Therefore, a greater understanding of how muscular activation profiles influence lower limb mechanics with respect to ACL injury risk factors is a central aspect to improving future injury prevention strategies. The purpose of this study was to identify the muscular activation profiles utilised by female athletes during a sport-specific landing task, and examine the effects of varying profiles on lower limb biomechanical variables that have been linked to ACL injury risk.

METHODS: Twenty-five female netball players (23.5 ± 3.0 yr; 171.0 ± 7.9 cm; 67.6 ± 9.0 kg), free of current injury and no history of ACL injury participated in this study. The sport-specific landing examined was a netball leap landing; which involved a six-metre run-up, followed by a single limb take-off and land on the contralateral limb while catching a pass (see Figure 1). Participants completed 20 successful trials, with 60-90 seconds rest allocated between trials.

Figure 1: Sagittal view of sport-specific leap landing task.

Wireless surface electromyography (EMG) data (Delsys Trigno, Delsys Incorporation, Boston, MA, United States) were recorded at 2000 Hz from eight lower limb muscles (gluteus maximus [GMAX], gluteus medius [GMED], medial hamstrings [MHAM], lateral hamstrings [LHAM], rectus femoris [RF], vastus lateralis [VL], vastus medialis [VM], lateral gastrocnemius [GAS]). All EMG data were exported to MATLAB (The Mathworks, Inc., Natick, MA, United States) and were full-wave rectified; filtered with a 20 Hz high-pass fourth-order zero-lag Butterworth filter; and converted to a linear envelop via a 6 Hz low-pass fourth-order zero-lag Butterworth filter. EMG data were amplitude normalised (% MVC) to peak activation recorded during maximal voluntary contractions. Muscular activation profiles were identified via a combination of principal component and cluster analysis procedures. EMG waveform data from 150 milliseconds (ms) prior to initial contact (IC), through to 300ms post IC were submitted to principal component analysis (PCA) as per Hubley-Kozey, Deluzio, Landry, McNutt, and Stanish (2006). Principal pattern scores (PP-Scores) were then computed for each activation pattern across each muscle. The PP-Scores from all landing trials were normalised via transformation to their correlation matrix and submitted to a *k*-means clustering algorithm to group trials with similar muscular activation characteristics. Three-dimensional (3D) kinematics and kinetics of the lower limb were computed using an established musculoskeletal model (McLean, Su, & van den Bogert, 2003). Kinematic and kinetic data were collected using an eight camera 3D motion capture system (Vicon, Oxford Metrics Limited, Oxford, United Kingdom) sampling at 250Hz, synchronised with a 600mm by 900mm in ground force platform (Advanced Medical Technology Incorporated, Watertown, MA, United States), sampling at 1000Hz. Hip, knee, and ankle joint rotations and normalised external joint moments from IC to 300ms post IC were calculated from filtered (fc = 12 Hz) marker trajectory and ground reaction force data within Visual 3D software (C-Motion, Rockville, MD, United States). Joint rotation and moment data were submitted to an identical PCA procedure as outlined above to identify lower limb biomechanical patterns during landing. The specific muscular activation and biomechanical differences between profiles were identified by submitting PP-Scores to one-way analysis of variance followed by post-hoc comparisons where necessary.

RESULTS AND DISCUSSION: Cluster validation (Caliński & Harabasz, 1974) revealed partitioning data into three groups provided the most distinct clustering solution; therefore, three muscular activation profiles (MAP-1, MAP-2, MAP-3) were identified (see Figure 2). Of the 500 total trials; 151, 181 and 168 were clustered to MAP-1, MAP-2 and MAP-3, respectively. Trials clustered to MAP-1 were characterised by greater preparatory activity of GMAX and GAS; high overall LHAM activation; and reduced overall activation of RF, VL and VM. Trials within MAP-2 demonstrated reduced GMAX, GMED, and LHAM preparatory activity; moderate GAS preparatory activity; high overall GMAX, GMED, MHAM, RF, VL and VM activation; peak MHAM, RF, VL and VM activation closer to IC; and greater LHAM activation after IC. Trials within MAP-3 were characterised by reduced GAS preparatory activity; low overall MHAM activation; moderate RF and VM activation; high overall VL activation; and peak RF, VL and VM activation further from IC.
Increases in frontal and transverse plane knee moments place a greater strain on the ACL during landing movements, thus increasing the risk of ACL injury (Oh, Lipps, Ashton-Miller, & Wojtys, 2012). Based on their anatomical moment arms, the hamstrings play an important role in supporting frontal and transverse plane knee moments during weight bearing knee flexion (Besier, Lloyd, & Ackland, 2003). Preparatory activity of the hamstrings has been acknowledged as an important factor in minimising ACL injury risk (Zebis, Andersen, Bencke, Kjaer, & Aagaard, 2009), and the results of this study appear to support this. Specifically, the magnitude and timing of preparatory activity of the hamstrings may have a modulating effect on the scale of frontal and transverse plane knee moments experienced during landing. Reduced preparatory activity of the LHAM and delayed preparatory activity of the MHAM were characteristic of MAP-2, with this profile demonstrating the largest frontal and transverse plane knee moments. While MAP-2 demonstrated greater hamstrings activation after IC, this may have been insufficient in counteracting the deficits in preparatory activity. Improving preparatory activation and timing of the hamstrings, therefore, may be an appropriate strategy for reducing potentially injuries knee moments during this landing task.

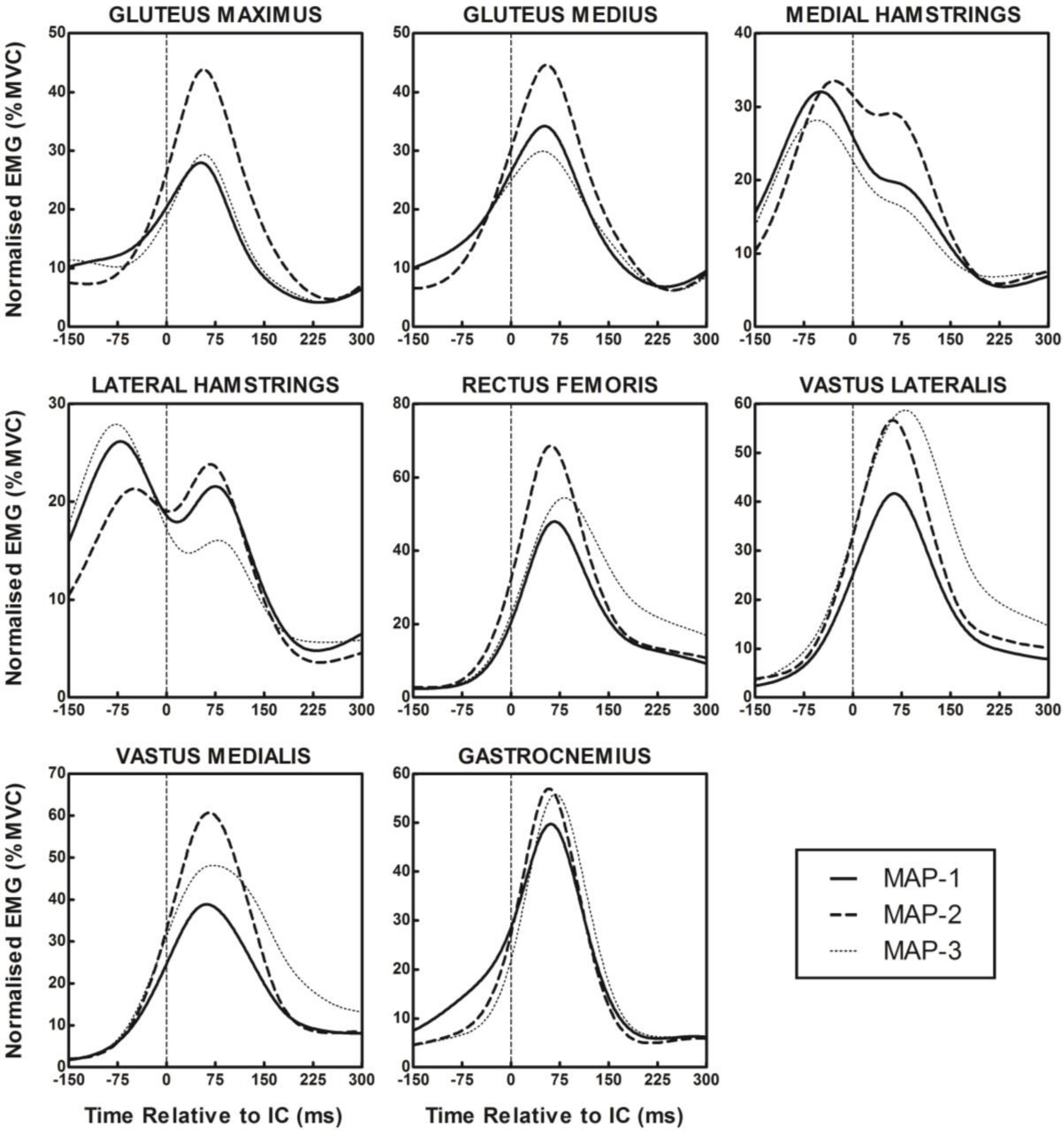

Figure 2: Average muscle activity of the three muscular activation profiles identified for the eight lower limb muscles examined. Dashed vertical line indicates initial contact (IC).

Lower knee flexion angles have also been linked with larger ACL strains during landing (Taylor et al., 2011). Trials within MAP-2 demonstrated reduced knee flexion at IC and reduced overall knee flexion displacement. Greater GMAX and quadriceps activation have been identified as factors in limiting knee flexion during landing (Walsh, Boling, McGrath, Blackburn, & Padua, 2012), with MAP-2 exhibiting these activation characteristics. Reduced overall GMAX and quadriceps activation was observed with MAP-1, with this profile recording the greatest magnitude of knee flexion. Thus, reducing the activation of these muscles may promote landings with greater knee flexion. While this may be the case, reducing hip muscle activation may have detrimental effects on proximal mechanics, affecting the entire lower extremity.

Large hip adduction and internal rotation during landing can cause medial knee displacement resulting in a valgus position (Powers, 2010), a known risk factor for ACL injury (Hewett et al., 2005). Greater hip adduction and internal rotation were observed with MAP-1 and MAP-2, with these profiles also experiencing greater knee valgus. The reduced activation of GMAX and GMED demonstrated by these profiles likely contributed to these hip motions and subsequent knee valgus. Both the GMAX and GMED can protect the knee by limiting hip adduction and internal rotation during landing (Powers, 2010). Increasing hip muscle activation may therefore be a viable method for improving mechanics at both the hip and knee. Considering the potential aforementioned role of GMAX in limiting knee flexion, increases in GMAX activation must be balanced with activation characteristics that promote knee flexion during landing.

CONCLUSIONS: Three muscular activation profiles were identified during a sport-specific landing task performed by female athletes. Deficits in preparatory activation of the hamstrings seen with MAP-2 appeared to contribute to larger frontal and transverse plane knee moments, which can place a greater strain on the ACL during landing. Decreased GMAX and GMED activation observed with MAP-1 and MAP-3 appeared to result in hip motions that placed the knee in a position associated with elevated ACL injury risk. Reduction of ACL injury risk may be achieved by targeting these muscular activation characteristics via neuromuscular training.

REFERENCES:

Besier, T.F., Lloyd, D.G., & Ackland, T.R. (2003). Muscle activation strategies at the knee during running and cutting maneuvers. *Medicine and Science in Sports and Exercise*, 35, 119-127.

Caliński, T. & Harabasz, J. (1974). A dendrite method for cluster analysis. *Communications in Statistics*, 3, 1-27.

Griffin, L.Y., Agel, J., Albohm, M.J., Arendt, E.A., Dick, R.W., Garrett, W.E., … Wojtys, E.M. (2000). Noncontact anterior cruciate ligament injuries: Risk factors and prevention strategies. *The Journal of the American Academy of Orthopaedic Surgeons*, 8, 141-150.

Hashemi, J., Chandrashekar, N., Jang, T., Karpat, F., Oseto, M. & Ekwaro-Osire, S. (2007). An alternative mechanism of non-contact anterior cruciate ligament injury during jump-landing: *In-vitro* simulation. *Experimental Mechanics*, 47, 347-354.

Hewett, T.E., Myer, G.D., Ford, K.R., Heidt Jr, R.S., Colosimo, A.J., McLean, S.G., … Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes. *American Journal of Sports Medicine*, 33, 492-501.

Hewett, T., Myer, G., Ford, K., Paterno, M. & Quatman, C. (2012). The sequence of prevention: A systematic approach to prevent anterior cruciate ligament injury. *Clinical Orthopaedics and Related Research*, 470, 1-11.

Hubley-Kozey, C.L., Deluzio, K.J., Landry, S.C., McNutt, J.S. & Stanish, W.D. (2006). Neuromuscular alterations during walking in persons with moderate knee osteoarthritis. *Journal of Electromyography and Kinesiology*, 16, 365-378.

McLean, S.G., Su, A. & van den Bogert, A.J. (2003). Development and validation of a 3-D model to predict knee joint loading during dynamic movement. *Journal of Biomechanical Engineering*, 125, 864-874.

Oh, Y.K., Lipps, D.B., Ashton-Miller, J.A., & Wojtys, E.M. (2012). What strains the anterior cruciate ligament during a pivot landing? *American Journal of Sports Medicine*, 40, 574-583.

Powers, C.M. (2010). The influence of abnormal hip mechanics on knee injury: A biomechanical perspective. *Journal of Orthopaedic and Sports Physical Therapy*, 40, 42-51.

Taylor, K.A., Terry, M.E., Utturkar, G.M., Spritzer, C.E., Queen, R.M., Irribarra, L.A., … DeFrate, L.E. (2011). Measurement of in vivo anterior cruciate ligament strain during dynamic jump landing. *Journal of Biomechanics*, 44, 365-371.

Walsh, M., Boling, M.C., McGrath, M., Blackburn, J.T., & Padua, D.A. (2012). Lower extremity muscle activation and knee flexion during a jump-landing task. *Journal of Athletic Training*, 47, 406-413.

Zebis, M.K., Andersen, L.L., Bencke, J., Kjaer, M. & Aagaard, P. (2009). Identification of athletes at future risk of anterior cruciate ligament ruptures by neuromuscular screening. *American Journal of Sports Medicine*, 37, 1967-1973.

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