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Single leg jumping neuromuscular control is improved following whole body, long-axis rotational training

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ABSTRACT

Improved lower extremity neuromuscular control during sports may decrease injury risk. This prospective study evaluated progressive resistance, whole body, long-axis rotational training on the Ground Force 360 device. Our hypothesis was that device training would improve lower extremity neuromuscular control based on previous reports of kinematic, ground reaction force (GRF) or electromyographic (EMG) evidence of safer or more efficient dynamic knee stability during jumping. Thirty-six healthy subjects were randomly assigned to either training (Group 1) or control (Group 2) groups. Using a pre-test, post-test study design data were collected from three SLVJ trials. Unpaired *t*-tests with adjustments for multiple comparisons were used to evaluate group mean change differences ($P \leqslant 0.05/25 \leqslant 0.002$). During propulsion Group 1 standardized EMG amplitude mean change differences for gluteus maximus (−21.8% vs. +17.4%), gluteus medius (−28.6% vs. +15.0%), rectus femoris (−27.1% vs. +11.2%), vastus medialis (−20.2% vs. +9.1%), and medial hamstrings (−38.3% vs. +30.3%) differed from Group 2. During landing Group 1 standardized EMG amplitude mean change differences for gluteus maximus (−32.9% vs. +11.1%) and rectus femoris (−33.3% vs. +29.0%) also differed from Group 2. Group 1 peak propulsion vertical GRF (+0.24 N/kg vs. −0.46 N/kg) and landing GRF stabilization timing (−0.68 vs. +0.05 s) mean change differences differed from Group 2. Group 1 mean hip (−16.3 vs. +7.8°/s) and knee (−21.4 vs. +18.5°/s) flexion velocity mean change differences also differed from Group 2. Improved lower extremity neuromuscular efficiency, increased peak propulsive vertical GRF, decreased mean hip and knee flexion velocities during landing, and earlier landing stabilization timing in the training group suggests improved lower extremity neuromuscular control.

1. Introduction

Lower extremity injuries sustained during sports can lead to long-term, and/or permanent physical health impairments (Hootman et al., 2007). Potentially injurious alignment and excessive joint forces associated with poor lower extremity neuromuscular control may increase injury risk (Pollard et al., 2010). Anterior cruciate ligament (ACL) injuries in particular often occur from non-contact injury mechanisms, such as jump landings (Yu et al., 2002).

The single leg vertical jump (SLVJ) is a sports movement that requires lower extremity neuromuscular control to be performed safely (Williams et al., 2001; Yu et al., 2002). The loading response that occurs as the foot impacts the ground during single leg jump landings creates a chain reaction through multiple lower extremity joint linkages (Powers, 2003; Pollard et al., 2010; Yu et al., 2002). Lower extremity neuromuscular control represents unconscious efferent responses to afferent signals that help dampen or mitigate lower extremity joint loads facilitating dynamic joint stability (Lephart et al., 2000; Williams et al., 2001). Improving trunk-lower extremity neuromuscular control using exercises that closely simulate sport movements is an essential component of many lower extremity injury prevention training programs (Imwalle et al., 2009; Myer et al., 2008).

Evidence supporting improved lower extremity neuromuscular efficiency using conventional progressive resistance exercises that do not closely replicate specific sport movements has been previously reported (Bruhn et al., 2004; LaStayo et al., 2008). Following 8 weeks of submaximal effort eccentric cycling ergometry in healthy subjects, LaStayo et al. (2008) identified decreased vastus lateralis EMG amplitudes suggesting a reduced neural drive requirement to withstand higher knee loads. In having healthy subjects perform twice weekly maximum effort leg presses over 4 weeks, Bruhn et al. (2004) observed decreased gastrocnemius, peroneus longus, and tibialis anterior EMG amplitudes in association with improved single leg postural stabilization times, and decreased sway displacement during single leg stance on a swinging platform. During unfatigued conditions EMG signal amplitude is generally proportional to muscle force (de Vries, 1968). Therefore,

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more efficient muscle activation requires a lesser amount of a given muscle's total activation capacity to perform the same task with the same level of neuromuscular control, as a weaker, or less efficient muscle (Hof, 2003).

Previous studies have revealed efficient lower extremity neuromuscular control during countermovement jump performance in healthy men through muscle activation efficiency, lower extremity angular displacement, and lower extremity angular velocity regulation (Bosco et al., 2000, 1982; Bosco and Viitasalo, 1982). Reduced lower extremity neuromuscular control has been observed among patients following unilateral ACL reconstruction through decreased propulsive SLVJ vertical ground reaction forces (Myer et al., 2006; Paterno et al., 2007). Reduced lower extremity neuromuscular control has also been observed among healthy athletes considered to be at risk for ACL injury (Alentorn-Geli et al., 2009) and among individuals following unilateral ACL reconstruction (Paterno et al., 2007) through increased jump landing vertical ground reaction forces. In a study of 13 subjects at a mean 3.3 years following unilateral ACL reconstruction reduced lower extremity neuromuscular control was indicated by a significantly greater time needed at the surgical lower extremity compared to the non-surgical lower extremity to achieve postural stabilization during a single leg step down task from a 19 cm tall step (Colby et al., 1999). Increased knee injury risk when jumping has been related to decreased hip and knee flexion angles at initial landing (Hewett et al., 2006; Pollard et al., 2010). Increased peak hip and knee flexion angular displacement among subjects with long-term ACL deficiency has also been reported as kinematic compensations to increase lower extremity neuromuscular control during one-leg hop for distance performance (Gauffin and Tropp, 1992). The ability to reduce hip and knee flexion velocity during jump landings has also been related to improved lower extremity neuromuscular control and decreased knee injury risk among athletically active individuals (Hewett et al., 2006).

Through the application of progressive concentric and eccentric resistance, and range of motion during whole body, long-axis rotation, the Ground Force 360 Device (Center of Rotational Exercise, Inc., Clearwater, FL) was designed to improve trunk-lower extremity neuromuscular control during simulated sport movements (Fig. 1). During upright, weightbearing function, trunk and lower extremity movements, load transfer, and muscle power are directly coupled (Gracovetsky, 1997; Gracovetsky and Iacono, 1987; van Wingerden et al., 1993; Vleeming et al., 1995). Therefore long-axis trunk rotation occurs in synchrony with lower extremity movements. Through tendon insertions and fascial connections, gluteus maximus and hamstring neuromuscular activation in particular is highly integrated with axial trunk rotation (van Wingerden et al., 1993; Vleeming et al., 1995). Knee injury prevention studies have identified direct relationships between neuromuscular trunk control deficits and increased knee injury risk (Zazulak et al., 2007a,b). As movement patterns become more automatic through effective practice they become more neuromuscularly and biomechanically efficient (Wu et al., 2008). Enhanced neuromuscular connectivity is considered to be the primary reason for improved efficiency (Green and Wilson, 2000; Wu et al., 2008). The close association between trunk and lower extremity movements, load transfer, and muscle power during the whole body, long axis rotation that occurs with Ground Force 360 Device training may simulate the coordinated trunk and lower extremity function that occurs during jump landings. The concentric-to-eccentric exercise mode in particular was considered a potentially useful setting for simulating the concentric-to-eccentric muscle activation of SLVJ propulsion and landing. Foot position was adjusted between exercise sets from standard athletic ready position placement (at or slightly greater than shoulder-width apart) to diagonal placement (stride position with the left foot forward for concentric left rotation and with the right foot forward for concentric right rotation) to modify frontal and transverse plane lower extremity alignment and better facilitate hip abductor-adductor and internal-external rotator neuromuscular contributions (Neumann, 2010). Training with this device may provide a useful, non-impact method for increasing the lower extremity neuromuscular control needed to improve dynamic knee stability during single leg jumping.

The purpose of this study, which represents part of a larger project, was to evaluate the efficacy of using progressive resistance, whole body, long-axis rotational training to improve the lower extremity neuromuscular control that enhances the dynamic knee stability of healthy subjects during SLVJ propulsion and landing. The study hypothesis was that the training group would display significantly greater mean change differences identifying improved lower extremity neuromuscular control and enhanced dynamic knee stability compared to the control group.

2. Methods

2.1. Experimental design

This was a prospective, randomized controlled study using a pre-test, post-test design with statistical comparison of mean change differences between data collection sessions. The time period between pre-test and post-test measurements was 4.0 ± 0.5 weeks (range = 3.5–5 weeks) for both groups.

2.2. Subject recruitment and group assignment

The Institutional Review Boards of the University of Louisville and Norton Healthcare, Louisville, KY approved this study. An a priori sample size calculation based on pilot test data was performed. Using the "unit-less" method of EMG standardization described in the methods section, a mean change difference of 10 with a standard deviation of 5 in the device training group and a mean change difference of 3 with a standard deviation of 5 in the control group produced an effect size of 1.4. Based on this estimate a minimum of 17 subjects were needed in each group with a directional hypothesis at a beta error level of 0.80 and an alpha error level of $P = 0.002$. To be considered for study inclusion subjects had to be between 18 and 50 years of age, be regularly participating in an exercise program or sports activity at least twice weekly, be without low back injury history or current low back pain, be without current lower extremity injury, and have no history of lower extremity surgery other than partial menisectomy (and be at least 2 years post-surgery).

Written informed consent was obtained from each subject. Forty-six potential subjects responded to campus flyer advertisements. Ten potential subjects were rejected from study participation because of previous knee ligament reconstruction, low back injury history, the desire to increase existing exercise program or sports activity volume during the study period, or because of an inability to comply with the study time commitment. Using a random numbers table with block randomization for gender, subjects were assigned to the device training group (Group 1) or to a control group (Group 2). Subject perceived activity level was determined using the International Knee Documentation Committee (IKDC) Activity Scale (1 = highly competitive sports person, 2 = well-trained and frequently sporting, 3 = sporting sometimes, 4 = non-sporting) (Table 1). Subjects continued regular exercise program or sport activities during the study period without increasing intensity, frequency, or volume. Female subjects were required to provide a negative pregnancy test at study initiation. Based on allocated time requirements, training group subjects were reimbursed