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Agonist versus antagonist muscle fatigue effects on thigh muscle activity and vertical ground reaction during drop landing

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Abstract

Background: Agonist and antagonist co-activation plays an important role for stabilizing the knee joint, especially after fatigue. However, whether selective fatigue of agonists or antagonist muscles would cause different changes in muscle activation patterns is unknown.
Hypothesis: Knee extension fatigue would have a higher influence on landing biomechanics compared with a knee flexion protocol.
Study design: Repeated-measures design.
Methods: Twenty healthy subjects (10 males and 10 females) performed two sets of repeated maximal isokinetic concentric efforts of the knee extensors (KE) at $120^\circ\ s^{-1}$ until they could no longer consistently produce 30% of maximum torque. On a separate day, a similar knee flexion (KF) fatigue protocol was also performed. Single leg landings from 30 cm drop height were performed before, in the middle and after the end of the fatigue test. The mean normalized electromyographic (EMG) signal of the vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF) and gastrocnemius (GAS) at selected landing phases were determined before, during and after fatigue. Quadriceps:hamstrings (Q:H) EMG ratio as well as sagittal hip and knee angles and vertical ground reaction force (GRF) were also recorded.
Results: Two-way analysis of variance designs showed that KE fatigue resulted in significantly lower GRF and higher knee flexion angles at initial contact while maximum hip and knee flexion also increased ($p < 0.05$). This was accompanied by a significant decline of BF EMG, unaltered EMG of vastii and GAS muscles and increased Q:H ratio. In contrast, KF fatigue had no effects on vGRFs but it was accompanied by increased activation of VM, BF and GAS while the Q:H increased during before landing and decreased after impact.
Conclusion: Fatigue responses during landing are highly dependent on the muscle which is fatigued.

Keywords: Electromyography; Anterior cruciate ligament; Co-activation; Injury prevention

1. Introduction

Landing from a jump is a common activity in sport and work environments. The vertical ground reaction force (GRF) during single-leg landings is high and it can reach 11 times body weight (McNitt-Gray, 1991). This mechanical shock must be attenuated by the musculoskeletal system. However, when the external loads are very high for the body to adequately attenuate, the probability of injury increases (Devita and Skelly, 1992; Dufek et al., 1990; Dufek and Bates, 1991; Gross and Nelson, 1988; James et al., 2000; Kovacs et al., 1999).

Fatigue has been hypothesized to alter the biomechanical and neuromuscular factors associated with the risk of sustaining musculoskeletal injury (Christina et al., 2001; Rozzi et al., 1999a). Epidemiological and experimental studies indicate that fatigue combined with extreme loads, may lead to injury (Pettrone and Ricciardelli, 1987; Urabe et al., 2005). Fatigue affects reaction time (Hakkinen and Komi, 1986), movement co-ordination and motor control precision (Sparto et al., 1997), and reduces the muscle force generation capacity (Nicol et al., 1991a).

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The ground reaction force (GRF) provides an indication of the loading of the musculoskeletal system after fatigue; more importantly, because the GRF is greater during a stiffer landing, GRF has be used to identify changes in landing stiffness (Madigan and Pidcoe, 2003; Padua et al., 2006; Tillman et al., 2004). Research has shown that vertical GRF during single-leg landing decreases after fatigue (Madigan and Pidcoe, 2003) while vertical leg stiffness remains unaltered (Padua et al., 2006). The reduction of vertical GRF after fatigue is indicative of the subject effort to reduce the mechanical shock due to landing.

Since landing is a multiarticular task, subjects may use altered activation and movement strategies to account for fatigue effects. Previous research has shown that post-fatigue landing is characterised by increased flexion of the knee (Coventry et al., 2006; Madigan and Pidcoe, 2003) and the hip (Coventry et al., 2006) and decreased ankle plantarflexion (Coventry et al., 2006). An increase in knee flexion acceleration has also been reported (Fagenbaum and Darling, 2003). Fatigue also caused a re-distribution of work produced around the lower limb joints, as hip joint work increased, knee joint remained unaltered while ankle work decreased after fatigue (Coventry et al., 2006; Madigan and Pidcoe, 2003).

The alterations in kinetics and kinematics after fatigue may be the result of alterations in muscle activation profiles of the associated musculature. Despite this, only a few studies have examined muscle activation profiles during single-leg landings after fatigue (Padua et al., 2006; Rozzi et al., 1999b). Particularly, increased co-contraction of antagonistic musculature around the knee and the ankle (Padua et al., 2006) and alterations in contraction onset of knee and ankle muscles (Rozzi et al., 1999b) have been reported. Among numerous strategies available, Padua et al. (2006) identified three strategies to control joint motion after fatigue: the ankle-dominant strategy where individuals place greater reliance on the ankle musculature; the antagonist inhibition strategy which is characterised by a decline in antagonist muscle activation patterns upon landing and, finally, the quadriceps-dominant strategy where subjects place greater reliance on quadriceps muscles after fatigue. It seems, therefore, muscle activation responses to fatigue mainly focus around the activity patterns of the quadriceps and hamstrings. However, it is known that these co-contraction of the agonist–antagonist muscle groups around the knee is an important determinant of knee joint stability (Kellis, 1998). For these reasons, examination of fatigue effects on activation of agonist–antagonist couple of muscles is worthwhile.

Evidence suggests that agonist fatigue affects movement kinematics more than antagonist muscle fatigue (Jaric et al., 2000; Rodacki et al., 2002). For example, Rodacki et al. (2002) reported that fatiguing the knee flexor muscles did not change the kinematic, kinetic, and electromyographic profiles of counter movement jumps. In contrast, knee extensor fatigue caused the subjects to adjust several variables of the movement. These results, however, apply to countermovement jumps where individuals aim to maximize jumping performance. This differs compared with drop landings where safe landing is the main priority. Single-leg landings are characterised by high pre-activation of vastus medialis, hamstrings and lateral gastrocnemius muscles (Cowling and Steele, 2001; Tillman et al., 2004) in order to stabilize the knee and the ankle in preparation for landing. The majority of previous studies examined landing biomechanics after fatiguing mainly the knee extensor musculature (Fagenbaum and Darling, 2003; Madigan and Pidcoe, 2003; Padua et al., 2006; Rozzi et al., 1999b; Wikstrom et al., 2004). To our knowledge, muscle activation and kinematics during singe leg landing following different muscle fatigue protocols have not been examined. Taken into account the potentially different roles of agonist and antagonist muscle action during landing, it can be assumed that selective fatigue of either of them would cause different changes in movement biomechanics. Such information may provide an insight on the way the neuromuscular system adjusts the movement co-ordination pattern used during landing under fatigue of different muscles. The objective of this study was to compare the effects of a knee extension (KE) and flexion (KF) fatigue protocol on vertical GRF and EMG characteristics during landing. It was hypothesized that KE fatigue would have a higher influence on vertical GRF, kinematic and EMG variables compared with KF protocol.

2. Methods

2.1. Design

A single two-group pre-post test design was applied. The subjects visited the laboratory three days, a week apart. The aim of the first visit was to familiarize the subjects with isokinetic dynamometer and landing technique. Day 1 was a familiarisation session whereas the KE (agonist) and KF (antagonist) isokinetic fatigue protocols were performed on the next two sessions on a random basis. Vertical GRF, muscle EMGs and hip and knee kinematics were recorded prior to and after fatigue.

2.2. Subjects

Ten males (age 24.3 ± 1.25 yr, height 181.3 ± 8.27 cm, body mass 79 ± 8.21 kg) and ten females (age 23.5 ± 1.43 yr, height 168.9 ± 8.38 cm, body mass 59.82 ± 6.25 kg) who were physical education students volunteered to participate. The participants had no history of serious lower-extremity injury. Subjects signed informed written consent prior to their participation. The study was approved by the Aristotle University Ethics Committee.

2.3. Instrumentation

All drop landings were performed on a customized uni-axial force plate (600×400 cm). The platform uses a strain gauge (Model LC4204 – K600, A&D Co. Ltd., Tokyo, Japan) capable to measure vertical ground reaction force (linearity <0.6% of full scale deflection; hysteresis <1% of full scale deflection; range 0–7 KN; overload = 14 KN; natural frequency >650 Hz). The ana-