Journal of Electromyography and Kinesiology 21 (2011) 506–511

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

Differences in time–frequency representation of lower limbs myoelectric activity during single and double leg landing in male athletes

Gustavo Leporace [a,b,c], Glauber Ribeiro Pereira [a,c], Jurandir Nadal [c], Luiz Alberto Batista [a,d,*]

[a] Laboratory of Biomechanics and Motor Behavior, State University of Rio de Janeiro, Rio de Janeiro, Brazil
[b] Institute Brazil of Health Technology, Rio de Janeiro, Brazil
[c] Laboratory of Images and Signal Processing, Biomedical Engineering Program-COPPE, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
[d] Graduate Program on Medical Sciences, State University of Rio de Janeiro, Rio de Janeiro, Brazil

ARTICLE INFO

Article history:
Received 29 June 2010
Received in revised form 28 October 2010
Accepted 2 December 2010

Keywords:
Biomechanics
EMG
Time–frequency representation
Landing
Anterior cruciate ligament

ABSTRACT

This study compared the instantaneous median frequency (IMF) obtained by means of a Choi-Williams transform of an electromyogram of the lower-limb muscles during single-leg (SL) and double-leg (DL) landings performed by fifteen male athletes. The IMF values of the rectus femoris (RF), biceps femoris (BF) and hip adductors (HA) were compared between two landing tasks, within each landing, and before and after ground contact (GC). The IMF values of the RF did not change between landings in contrast to those of the BF, which presented from 20- to 40-ms higher SL values before GC and from 40 to 60 ms after GC. HA presented higher SL values during the 40–60 ms range before GC. Within each landing, the RF IMF decreased from 40 ms to 60 ms after GC in the SL. Similar results were found for the HA IMF, which decreased from 40 ms to 80 ms after GC. The BF IMF showed no significant change. These results suggest muscle recruitment related to anterior cruciate ligament protection since the IMF values of the RF decreased in the SL, whereas the BF IMF increased. Results for the HA showed the importance of hip muscles in stabilizing the core region, allowing the activation of distal muscles with greater safety.

1. Introduction

Although much attention has been devoted to discovering the causal and predictive factors related to anterior cruciate ligament (ACL) injury, the available data support few conclusive results (Alentorn-Geli et al., 2009). A variety of evidence associates anatomical, hormonal and environmental factors to this lesion (Griffin et al., 2006; Renstrom et al., 2008). However, the neuromuscular and biomechanical characteristics are primarily studied because many variables can be modified by an adjusted training strategy (Renstrom et al., 2008). This approach has shown great effectiveness in reducing the incidence of injuries (Grindstaff et al., 2006).

Among the biomechanical variables, the knee valgus and the flexion angle during landing tasks, which are both associated with vertical ground reaction forces, present a greater causal relationship with ACL injuries, evidenced by prospective epidemiological (Hewett et al., 2005a), in vitro (Withrow et al., 2006) and simulation (McLean et al., 2008; Shin et al., 2009) studies.

Neuromuscular variables have assumed an important role in recent years. Although studies have already demonstrated that excessive activation of the quadriceps muscle, in relation to the hamstrings, increases tension in the ACL in controlled laboratory conditions (Draganich and Vahey, 1990; Li et al., 1999; DeMorat et al., 2004), only recently has a study shown a direct relationship between quadriceps/hamstring activation rates and ACL injuries (Zebis et al., 2009).

Another neuromuscular characteristic that has been extensively investigated is the relationship between the lumbar-pelvic region control, also called core region, and ACL injuries. Leetun et al. (2004) showed a strong correlation between trunk and hip muscle strength and knee injuries. Zazulak et al. (2007) reported that factors related to core stability, such as trunk displacement and proprioception, predicted ACL injuries in women, with 91% sensitivity and 68% specificity.

Recently, new strategies for myoelectric signal processing related to the time–frequency representation (TFR) have been applied, revealing valuable information and important interpretations concerning the motor units (MU) recruitment (Von Tscharner and Goepfert, 2003; Wakeling et al., 2002).

Several techniques have been developed to analyze changes in the signal spectral characteristics over time, among them is the exponential distribution proposed by Choi and Williams (1989), which belongs to the Cohen class of transforms (Cohen, 1989). The use of this class of transforms allows the estimation of new parameters, such as the instantaneous median frequency (IMF)

* Corresponding author at: Laboratory of Biomechanics and Motor Behavior, State University of Rio de Janeiro, Rua São Francisco Xavier, 524, Room 8122, P.O. Box 20550-090, Maracanã, Rio de Janeiro, Brazil. Tel.: +55 21 2334 0592.
E-mail address: batista.l.a@gmail.com (L.A. Batista).

1050-6411/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jelekin.2010.12.001

and the instantaneous power (Choi and Williams, 1989). The IMF corresponds to the frequency value that divides the instantaneous power into two equal parts at each time instant. Based on these definitions, it was proposed to use the IMF, as an alternative to the Fourier median frequency, to monitor the Choi–Williams distribution's (CWD) spectral content (Roy et al., 1998; Molinari et al., 2006).

While some authors suggest that the instantaneous mean and median frequencies would be related to the conduction velocity of the electrical potential in the muscle fiber and, consequently, to the muscle fiber type (Wakeling et al., 2002; White et al., 2003; Wakeling and Rozitis, 2004), other authors affirm that this relationship is not observed in dynamic situations (Farina et al., 2002; Merlo et al., 2005). However, recent studies with more controlled experimental models have confirmed the relationship between the frequency of activation, measured by the TFR of EMG signals, and the predominance of active MU during muscle contraction (Wakeling, 2009).

Of all the studies that discussed the MU recruitment by means of TFR, only one has examined motor tasks similar to those related to ACL injuries. Beaulieu et al. (2008) showed that during running, with unanticipated changes of direction, women showed lower values than men for the instantaneous mean frequency in hamstrings muscles. Similar results were presented by von Tscharner and Goepfert (2003) and White et al. (2003) during running tasks and knee flexion/extension on an isokinetic dynamometer, respectively. These authors concluded that these muscle recruitment strategies reduce the efficiency of the muscles around the knee in generating co-contraction and, consequently, stabilize the joint, pre-disposing women to ACL injuries.

No study was found to have examined muscle coordination related to different mechanical constraints, such as single-leg (SL) and double-leg (DL) landings. When measured in individuals with low-ACL injury risk, this information becomes valuable for developing different but effective and safe strategies for muscle recruitment, providing a reference basis for comparison with other populations with increased risk, such as female athletes.

The purpose of this study was to compare the IMF, obtained from the CWD of lower limb muscle EMG signals, between SL and DL landings in males. It was hypothesized that athletes would present different muscle recruitment strategies between landings with higher IMF values for hamstrings and HA and lower values for the rectus femoris during SL compared to DL. Because SL landings require the entire weight of the body to be supported by only one lower limb, an increased need for joint stabilization is required, condition that is decreased during DL landings.

2. Materials and methods

Fifteen male athletes from a regional volleyball team (age, 13 ± 1 year, height, 1.70 ± 0.12 m and weight, 60 ± 12 kg), with at least three years of experience playing volleyball, participated in this study. The athletes had no history of ligament injuries, nor had they reported pain at the time of the tests. All the players' parents signed an informed consent form allowing participation in the study. This study was approved by the State University of Rio de Janeiro Research Ethics Council.

Each subject performed two types of vertical jumps using both legs for propulsion and SL or DL landing (Fig. 1). The athletes performed the actions initially to familiarize themselves with the studied motor tasks. Thereafter, each athlete performed three landings with the dominant leg and three with both legs. Dominance was determined by questioning the athletes about their preferred leg for kicking a ball. The order of the jumps was randomized to minimize the possible effects of fatigue or learning. A one minute interval was allowed among trials. The EMG was captured from muscles of the dominant leg.

Ag/AgCl surface KOBME electrodes (Bio Protection, Korea) were positioned on the rectus femoris (RF), biceps femoris (BF) and hip adductors (HA) according to Cram et al. (1998). HA electrodes refer to the activity of adductor longus and gracilis muscles. RF electrodes were placed 2 cm apart, parallel to muscle fibers on the center of the anterior surface of the thigh, at approximately half the distance between the knee and the anterior superior iliac spine. BF electrodes were placed 2 cm apart, parallel to muscle fibers in the lateral thigh surface, approximately two-thirds the distance between the greater trochanter and the posterior knee joint. Finally, HA electrodes were positioned parallel to the muscle fibers in an oblique direction, 2 cm apart on the medial aspect of the thigh, approximately 4 cm from the pubis.

Before the application of the electrodes, the skin was prepared by shaving the area and cleansing with alcohol to reduce surface impedance. To prevent movement artifacts in the signals, the electrode cables were fixed to the skin using adhesive tape (3M, Brazil).

The EMG of all muscles were captured (EMG 100B, BIOPAC Systems, USA), amplified (differential bipolar amplification, input impedance = 2 MΩ, CMRR > 110 dB, gain = 1000), converted from analog to digital (12 bit, 2 kHz, MP100WSW BIOPAC Systems, USA) and stored on a personal computer.

To determine the initial ground contact, an electrical circuit was structured so that a terminal located in the sole in the first metatarsus region of the subject's shoe emitted a digital electrical signal upon contact with a metal platform fixed in the ground that was then captured by the UMI 100B module (BIOPAC Systems, USA).

The EMG signals were filtered by a 4th-order Butterworth filter (20–400 Hz), applied in direct and reverse directions to avoid phase distortions. After that, the CWD was obtained from 100-ms before initial ground contact (BGC) to 100-ms after initial ground contact (AGC). Mean IMF values were thus calculated for each 20-ms interval of the selected signal, totaling ten values (Table 1). The discrete CWD is given by:

$$CW(n,\theta) = 2\sum_{\tau=-\infty}^{\infty}\omega_n(\tau)e^{-j\theta\tau}\left(\sum_{\mu=-\infty}^{\infty}\omega_m(\mu)\frac{1}{\sqrt{\frac{4\pi\tau^2}{\sigma}}}e^{\frac{-\mu^2}{\frac{4\tau^2}{\sigma}}}(R(t,\tau))\right) \quad (1)$$

where $\omega_n(\tau)$ is a symmetric window that presents non zero values in the $-N/2 \leqslant \tau \leqslant N/2$ interval, $\omega_m(\mu)$ is a Hamming window along the $-M/2 \leqslant \mu \leqslant M/2$ interval, R is the instantaneous autocorrelation function, represented by $x(n+\mu+\tau)\,x^*(n+\mu-\tau)$, and σ is a scaling factor ($\sigma = 1$). MATLAB version 6.5 (The Mathworks, USA) was used for signal processing.

As IMF values did not show adherence to a Gaussian distribution (Kolmogorov–Smirnov test), the paired mean IMF values between SL and DL were compared using the Wilcoxon Ranked Test. The Friedman's analysis of variance test with the post hoc test of Dunn was used to compare the IMF behavior between each 20-ms interval within each landing test.

The significance level determined for this study was at 5%. All statistical analyses were performed using the software Statistical Package for Social Sciences for Windows (version 13.0, SPSS, Chicago, IL).

3. Results

3.1. Comparison of IMF values between SL and DL landings

The RF showed no significant differences in the IMF values between the landings in any situation (Table 2 and Fig. 2a). The BF showed significant differences between the landings in two intervals: BGC2 and AGC3. The values of IMF were higher for the SL