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Trunk Fatigue Profile and Low Back Pain in Tennis Players

Dissertação elaborada com vista à obtenção do Grau de Mestre em Ciências da Fisioterapia

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ABSTRACT

Introduction

The trunk plays an important role in tennis strokes. Its asymmetric muscle activation, coupled with the high repeatability of the sport, places tennis players at risk for injuries such as low back pain.

Objectives

This study aimed to present a trunk fatigue profile in tennis players and verify its association with low back pain (LBP).

Material and Methods

35 tennis players completed an isometric trunk endurance protocol comprising four tasks, each one directed at a trunk muscle group (flexors, extensors and rotators). Low back Pain (LBP) history was obtained through the Nordic Musculoskeletal Questionnaire. Surface electromyography (EMG) activity was recorded bilaterally from rectus abdominis, external obliques and two portions of erector spinae. Average electromyographic amplitude (avrEMG) and median frequency (MF) values were determined for each muscle. Changes in both parameters over time, avrEMG average and MF slope were used as indicators of muscle activation and fatigue.

Results and discussion

A high prevalence of LBP was detected. Greater flexor and right EO endurance was observed in healthy subjects. LBP subjects showed less activation of the ES and dominant EO. This muscle’s degree of activation was also negatively correlated with LBP history. Healthy subjects had greater activity of the nondominant RA.

Conclusion

These results support the importance of increased activity of various trunk muscle activity in dynamic stability and the concept of load sharing in LBP subjects.

Keywords: trunk, tennis, fatigue, low back pain

RESUMO

Introdução

O tronco desempenha um papel importante na execução das pancadas no ténis. A activação muscular assimétrica, juntamente com a execução repetida destes gestos, coloca os tenistas em risco de desenvolver lesões como dor lombar (DL).

Objectivos

Este estudo teve como objectivo apresentar um perfil de fadiga muscular do tronco e a sua associação com queixas de dor lombar (DL).

Material e métodos

35 tenistas completaram um protocolo de avaliação isométrico do tronco constituído por quatro tarefas dirigidas a diferentes grupos musculares (flexores, extensores e rotadores). A informação sobre antecedentes de DL foi obtida através do Questionário Musculoesquelético Nórdico. A actividade electromiográfica (EMG) foi recolhida bilateralmente no recto abdominal, oblíquo externo e duas porções dos extensores da coluna. Foram calculados os valores da amplitude electromiográfica média (avrEMG) e mediana da frequência (MF) para cada músculo. As alterações nestes parâmetros, o avrEMG médio e o declive da MF foram usados como indicadores da activação e fadiga musculares.

Resultados e discussão

Foi registada uma elevada prevalência de DL. Os sujeitos sem DL registaram uma maior resistência nos testes dos flexores e ponte lateral direita. Os sujeitos com DL mostraram uma menor activação da musculatura extensora e do oblíquo externo dominante. O grau de activação deste músculo mostrou uma correlação negativa com a presença de DL. Foi registada uma maior actividade do RA não dominante em sujeitos saudáveis.

Conclusão

Estes resultados apoiam a importância da activação dos vários grupos musculares do tronco para a estabilidade dinâmica da coluna e o conceito do *load sharing* em sujeitos com DL.

Palavras-chave: tronco, fadiga, ténis, dor lombar

TABLE OF CONTENTS

INTRODUCTION 8

  Literature review 8

  Objectives 15

MATERIAL AND METHODS 15

  Study design 15

  Sample selection 15

  Protocol 16

  Data collection 17

  Data processing 20

  Statistical analysis 22

RESULTS 23

  NMQ data 23

  Endurance time data 23

  EMG data 27

DISCUSSION 38

CONCLUSION 45

BIBLIOGRAPHY 46

APPENDIXES 53

ABBREVIATIONS LIST

avrEMG: average electromyographic amplitude
CMRR: common mode rejection ratio
EMG: electromyography
EO: external oblique
ES: erector spinae
ES-I: erector spinae (iliocostalis lumborum)
ES-L: erector spinae (longuissimus thoracis)
ICC: intraclass correlation coefficient
iEMG: integrated EMG
LBP: low back pain
LBP-7d: “low back pain in the last 7 days” condition
LBP-TR: “being unable to train or play because of low back pain in the last 12 months” condition
MF: median frequency
MRI: magnetic resonance imaging
MVC: maximum voluntary contraction
NMQ: Nordic Musculoskeletal Questionnaire
RA: rectus abdominis

INTRODUCTION

This document contains information concerning the study related to the Thesis of the Master in Physiotherapy Sciences. In the literature review section, the necessary background information available in the literature will be presented. The material and methods section contains the detailed description of all procedures performed during the study. After the presentation of the results, a discussion follows containing the implications of the findings and comparison to available data from other studies. Finally, the study's conclusions are stated.

Literature review

Trunk injury reports in tennis players refer a great variability of figures (3-50%) according to various authors (Alizadehkhaiyat, Fisher, Kemp, Vishwanathan, & Frostick, 2007; Bylak & Hutchinson, 1998; Chandler, Ellenbecker, & Roetert, 1998; Saccol et al., 2010; Silva et al., 2006). This disparity is thought to be caused by differences in the populations studied and in the definition of injury across those studies (Pluim et al., 2009; Pluim, Staal, Windler, & Jayanthi, 2006). However, there are studies which point to the relevance of trunk injuries in tennis practice. Fleisig, Nicholls, Elliott, & Escamilla, 2003 estimate that up to 50% of tennis players present with low back pain (LBP) lasting for at least a week; Van der Hoeven & Kibler, 2006 found that 31% (for young males) and 47% (for young females) of the limitations in training or playing tennis were related to LBP. Campbell, Straker, O'Sullivan, Elliott, & Reid, 2013 found, in a sample of Australian junior tennis players, that the average time of missed training because of LBP episodes was 34 days. Sheets, Abrams, Corazza, Safran, & Andriacchi, 2011 also point out that 38% of professional tennis players have had to interrupt their career at some time due to back pain.

The trunk injuries considered to be most common in tennis include abdominal and erector spinae (ES) muscle strains, rectus abdominis (RA) tears and pars interarticularis injuries (Bylak & Hutchinson, 1998; Chow, Park, & Tillman, 2009; Ellenbecker & Roetert, 2004; Sanchis-Moysi, Idoate, Dorado, Alayón, & Calbet, 2010; Swärd, 1992).

The main factor behind these injuries is the overuse and repetitive microtrauma of all musculoskeletal structures involved (Hjelm et al., 2010; Kibler & Safran, 2005), with tennis players performing as much as 1000 shots per match (Davey, Thorpe, Williams, & Thorpe, 2010).

Radiological trunk studies of tennis players document these musculoskeletal changes and also provide insight about risk factors for these injuries.

In a sample of 33 asymptomatic tennis players, Alyas, Turner, & Connell, 2007 found that 85% of the subjects had an abnormal lumbar MRI. The percentage of subjects presenting facet joint arthropathy, synovial cysts, disc degeneration and pars injuries was, respectively, 70%, 30%, 40% and 27%. Professional tennis players have been reported to show an asymmetric hypertrophy of the RA. A MRI study on these subjects revealed a 58% greater muscle volume of the RA in comparison to control subjects. Tennis players showed, on average, a 34% greater muscle volume of the dominant RA and an 85% greater muscle volume of the nondominant RA. The average difference in hypertrophy was 35%. This increased from the proximal to distal segments of the RA, from 18% on the first segment to 55% on the last (Sanchis-Moysi, Idoate, Dorado, Alayón, & Calbet, 2010). Connell et al., 2006 also found a hypertrophy of the nondominant RA in tennis players, and noted that most RA strains occurred in the distal segments of the nondominant side. The high and repeated demands imposed on the RA during the throwing and acceleration phase of the serve are thought to be the reason for this hypertrophy and the increase in EMG activity (Maquirriain, Ghisi, & Kokalj, 2007).

The trunk plays an important role in the kinetic chain of both the tennis serve and groundstrokes (Ellenbecker & Roetert, 2004; van der Hoeven & Kibler, 2006). The serve, as it is the only stroke over which the player has full control (Kibler & Safran, 2005), and forehand are regarded as being the most influential strokes in tennis (Bahamonde, 2000; Landlinger, Lindinger, Stöggl, Wagner, & Müller, 2010; Rota et al., 2012), and together comprise the majority of strokes executed during a match (Connell et al., 2006; Ellenbecker et al., 2010). It is estimated that the lower limbs and trunk are responsible for 51% of the kinetic energy and 54% of the force generated during the serve (Kibler, 1998).

In fact, as well as being a key stroke in tennis, the serve presents several musculoskeletal challenges to the trunk. During the wind-up phase of the serve, players perform a trunk hyperextension, lateral flexion and rotation movement away from the court before the acceleration phase. Although this movement allows for the ideal storage of elastic energy for the acceleration phase (Roetert et al., 2009), it places great stress on the posterior structures of the spine, and is thought to be the main causative factor for spondylolysis in tennis players (Ellenbecker et al., 2009). As previously stated, significant (eccentric) activity of the RA is important to support the trunk and avoid excessive stress to the spine. Afterwards, in the acceleration phase, a counter rotation occurs, eliciting forceful concentric activity of the trunk flexors and rotators. Finally, during the follow-through phase, eccentric control of the ES is necessary to assure a correct deceleration of the service motion (Chow et al., 2003; Chow et al., 2009; Roetert et al., 2009).

A more detailed analysis of the tennis serve allows for a better understanding of these demands. Trunk EMG studies of the serve reveal an asymmetrical pattern of activation across the various phases of the stroke. The nondominant RA was found to have a higher activity in all phases of the tennis serve (Chow et al., 2003). Bilateral differences were observed for the EO during the ascending wind-up and follow-through phases. For the ES, the descending windup and acceleration phases elicited the greatest asymmetry in activation (Chow, Shim, & Lim, 2003). Another trunk EMG analysis of the serve (Chow et al., 2009) also found a greater activity of the nondominant RA, predominantly during the descending wind-up. Bilateral differences of EO activity were also greater during this phase. ES muscles showed increased activity on the dominant side during the follow-through phase.

Biomechanical analyses of the tennis serve have found maximum trunk range of motion values during the serve to be between 8,3º and 31,9º for extension, 10,9º to 15,5º for lateral flexion and 4,1º to 11,2º of trunk rotation (Abrams, Harris, Andriacchi, & Safran, 2012; Chow et al., 2009), with upper trunk rotation speeds of up to 870ª/second and trunk angle decrease speeds of 280º/second (Fleisig et al., 2003). The back is the body region that endures the greatest amount of force during the tennis serve, withstanding forces during the serve between 2191 and 2986N, varying across serve types, generating torques between 685 and 885Nm. Abrams et al., 2012 found spinal compression and lateral forces, respectively, between 8,9 and 10,4N/kg and between 2,6 and 4,1N/kg. These authors also found that subjects with LBP withstood greater spinal lateral forces. This may be due to a lack of dynamic stability of the spine during the serve in these subjects.

Trunk muscle activation during the forehand has also been shown to be both elevated and asymmetric. Knudson & Blackwell, 2000 reported a significantly higher activation of the ES than that of the flexor muscles across all phases. These authors also found that the right EO showed the highest mean activation during the stroke. The greatest asymmetries in activation found were between the left and right ES during the forward swing, but in general there was a higher activation of the dominant RA and EO and nondominant ES. Rota et al., 2012 found that a delayed deactivation of the ES during the forehand was associated with greater ball speeds, which is probably associated with a longer backswing, allowing for more elastic energy to be stored. Increased activation of the RO had a similar association, showing the important role of the trunk in the force development in tennis strokes.

Trunk rotations during the groundstrokes at ball impact have been measured to be in the range of 87-106º (Reid & Elliott, 2002). Upper trunk rotation during the forehand can reach speeds of over 440º/second (Landlinger, Lindinger, Stöggl, Wagner, & Müller, 2010).

The nature of the demands in both the serve and groundstrokes previously described have been shown to create musculoskeletal asymmetries in various body regions of tennis players (Alizadehkhaiyat et al., 2007; Chandler et al., 1998; Ellenbecker et al., 2009; Ellenbecker & Roetert, 2004; Saccol et al., 2010; Silva et al., 2006), which have been associated with greater potential for trunk injuries (Ellenbecker & Roetert, 2004; Ng, Richardson, Parnianpour, & Kippers, 2002). Information about interlateral and antagonist muscle pairs and its connection with injury occurrence are important when designing injury prevention protocols (Chandler et al., 1998; Ellenbecker & Roetert, 2004; Hjelm et al., 2010).

Fatigue has also been shown to impair injury protection mechanisms and tennis performance, mostly because of loss of neuromuscular control, consequently decreasing the dynamic stability of the spine (Donatelli, Dimond, & Holland, 2012; Girard, Lattier, Micallef, & Millet, 2006; Hornery, Farrow, Mujika, & Young, 2007;

Kovacs, 2006). The lack of extensor endurance has been associated with the appearance of LBP episodes both in athletes and sedentary subjects (Arab, Salavati, Ebrahimi, & Ebrahim Mousavi, 2007; Biering-Sørensen, 1984; Evans, Refshauge, & Adams, 2007; O'Sullivan, 2005; Oddsson & De Luca, 2003; Reeves, Cholewicki, & Silfies, 2006; Renkawitz, Boluki, & Grifka, 2006).

Trunk muscular asymmetries in tennis players have been documented by some studies. In a sample of 82 tennis players performing a maximal trunk extension task, Renkawitz, Boluki, & Grifka, 2006 found that 85% subjects with LBP history had an integrated EMG (iEMG) of the dominant ES at least 30% higher than in the nondominant side, showing that tennis players activated their dominant ES more intensely even during a pure extension task. This percentage was reduced to 25% in healthy subjects. In a similar analysis performed on 70 amateur tennis players, Renkawitz, Linhardt, & Grifka, 2008 found the same percentage of subjects with increased iEMG of the dominant ES.

Isokinetic testing of tennis players' trunk flexion and extension concentric strength at 60º and 120º/second has produced flexion/extension strength ratios between 102 and 122%, for both males and females, in a sample of 60 junior tennis players. This shows tennis players produce greater flexion torques, unlike what is observed in healthy sedentary subjects, who usually show values under 100% (Roetert, McCormick, Brown, & Ellenbecker, 1996). On the other hand, a study of isometric trunk strength in 9 male tennis players showed a significantly higher maximal voluntary contraction in trunk extension (835N) than in flexion (638N), producing an extension/flexion ratio of 1,3. There was also a difference between left and right (557N) lateral bending. EMG analysis of the ES on these subjects revealed a significant increase in avrEMG (avrEMG) during an extension effort at 50% maximum voluntary contraction (MVC) for the left portion of the thoracic ES. The correspondent decrease in frequency was significant for both sides of the lumbar ES and the left side of thoracic ES (Swärd, Svensson, & Zetterberg, 1990). Adult sedentary subjects with LBP have showed greater fatigability (as expressed by a lower median frequency (MF) after an isometric trunk extension test) of the thoracic ES in comparison to its lumbar counterpart (Sung, Lammers, & Danial, 2009).

The study of the trunk isokinetic profile in 109 tennis players produced similar values for both left and right rotation. Left/right rotation ratios in this study were 0,95-0,98 for males and 0,94-0,98 for females (Ellenbecker & Roetert, 2004). This is in accordance with what is observed in both healthy and LBP sedentary subjects, although the latter have shown greater co-activation of the left EO and RA during the left rotation (Ng et al., 2002).

While the association between trunk muscle fatigue, activation asymmetries and LBP has not (to the author's knowledge) been previously documented in tennis players, some studies involving athletes of other sports have been performed. In golfers, Evans, Refshauge, Adams, & Aliprandi, 2005 found a trunk flexor endurance time 61% greater in healthy golfers than in those who had LBP symptoms. A difference greater than 12,5 seconds between side bridge endurance times was also shown to be a predictor for LBP in this study. A trunk muscle activation study in 35 male golfers revealed that subjects with LBP activated the ES significantly earlier during the backswing. This was attributed to a shift to a stabilization role by the ES in these subjects (Cole & Grimshaw, 2008a).

An association between LBP complaints and trunk muscle fatigue has also been documented in rowers. In a sample of 23 rowers, the MF value after a trunk extension task at 80% of the MVC for 30 seconds correctly identified which subjects had LBP (Roy et al., 1990). Another trunk EMG study indicated that rowers had a significant ES asymmetry between sides in the maximum activation level in a trunk extension task (Parkin, Nowicky, Rutherford, & McGregor, 2001). Chan, 2005 found a flexor/extensor endurance time ratio of 1,55 in a sample of intercollegiate rowers, which is a value above the normative value of less than 1 found by McGill, Childs, & Liebenson, 1999 in adult subjects without history of LBP.

A sample of 242 athletes revealed an asymmetric pattern of thoracic and lumbar ES activation amplitude during an extension task. 50% of the subjects with LBP had an asymmetric pattern, while in healthy subjects this percentage was only 30% (Reeves et al., 2006).

The isometric trunk endurance protocol proposed by McGill, Childs, & Liebenson, 1999 has been considered a safe, simple, reliable and cost-effective way of evaluating trunk endurance (Evans, Refshauge, & Adams, 2007; Oddsson et al., 1997). Individually, all the tests present high psychometric properties. These values, coupled with the protocol's relatively low equipment and facility demands, makes it a valid tool to be performed outside the laboratory setting.

The extensor (Biering-Sørensen) test has been widely cited in literature since its presentation by Biering-Sørensen, 1984 (Arab et al., 2007; Coleman, Straker, Campbell, Izumi, & Smith, 2011; Demoulin, Vanderthommen, Duysens, & Crielaard, 2006; Moreau, Green, Johnson, & Moreau, 2001; Pitcher, Behm, & Mackinnon, 2007). Test-retest ICC values ranged between 0,54 and 0,99 for healthy subjects and between 0,82 and 0,96 for physically active subjects with LBP (Moreau et al., 2001). The revision performed by Demoulin et al., 2006 showed test-retest ICC values higher than 0,75. Within-session and between-sessions reliability and intrarrater values were, respectively, 0,73, 0,68 and 0,99 for healthy subjects and 0,91, 0,88 and 0,99 for subjects with LBP. Arab et al., 2007 found, for both men and women, high values of sensitivity (0,92 and 0,84), specificity (0,76 and 0,74), positive (0,80 and 0,84) and negative (0,90 and 0,85) predictive values for this test. These results were obtained from a sample of 100 men and 100 women. The extensor test has been shown to correspond to 60% of the maximum voluntary contraction in healthy subjects (Moreau et al., 2001).

Psychometric analysis of the flexor test has shown reliability values of 0,97 in a sample of 75 healthy subjects (McGill et al., 1999) and an intrarrater ICC of 0,95 in a sample of 79 male and female athletes (Evans et al., 2007). Trunk flexion performed in the sagittal plane has been shown to elicit an isolated activation of the RA muscle (Konrad, Schmitz, & Denner, 2001).

For the side bridge test, the previously mentioned study of Evans et al., 2007 found an intrarrater ICC values of 0,82 for the left side bridge and of 0,85 for the right side bridge. McGill et al., 1999 found a reliability value of 0,99 for the side bridge test. Relatively to the physical demands of this test, Ekstrom, Donatelli, & Carp, 2007 determined that activation of the EO muscle was 69% of the MVC.

Objectives

To the author’s knowledge, no study has analyzed the association between fatigue of multiple trunk muscle groups (flexors, extensors and rotators) and LBP in tennis players. Therefore, the purposes of this study were 1) to provide a trunk muscle fatigue profile of tennis players that included various muscle groups; and 2) to assess whether any features of this profile had an association with low back pain complaints.

MATERIAL AND METHODS

Study design

This study follows a cross-sectional analytical design.

Sample selection

Thirty-seven tennis players volunteered to take part in the study. Thirty-five (28 male, 7 female, 18,54 ± 3,00 years old) met the inclusion criteria and were included in the final sample. Inclusion criteria were 1) being at least 16 years old; 2) a minimum of 3 years of tennis practice; 3) a minimum of 6 hours of tennis practice/week over the last season; 4) currently competing at least on a national level. Exclusion criteria were 1) history of surgery to the spine; 2) history of serious trunk musculoskeletal pathology (tumour, infection, structural scoliosis, spinal fracture); 3) practice of other sport 3 or more hours/week (excluding physical training); 4) being unable to assume testing positions. One subject was excluded due to previous surgery and one was unable to assume testing positions due to a recent ankle sprain. 34 out of the 35 subjects were right-handed. The full sample description is detailed in table 1.

Table 1 - Sample description.

	Minimum	Maximum	Mean±SD
Age (years)	16	28	18,54±3,00
Height (m)	1,56	1,97	1,76±0,09
Weight (kg)	50,90	93,00	68,80±9,85
BMI (kg/m^2)	18,69	26,31	22,04±1,85
Years of practice	3	24	9,7±4,12
Practice hours/week	6	40	17,06±8,95

Protocol

Subjects were measured for height and weight and completed a trunk endurance protocol as described by McGill, Childs, & Liebenson, 1999, comprising four isometric tests (trunk flexor test, extensor (Biering-Sørensen) test and left/right side bridge). All measurements and tests were performed by the same investigator at seven tennis clubs nationwide.

The flexor test was performed with the subjects in 60º of trunk flexion and 90º of hip and knee flexion, with a fixation strap over the feet (figure 1).

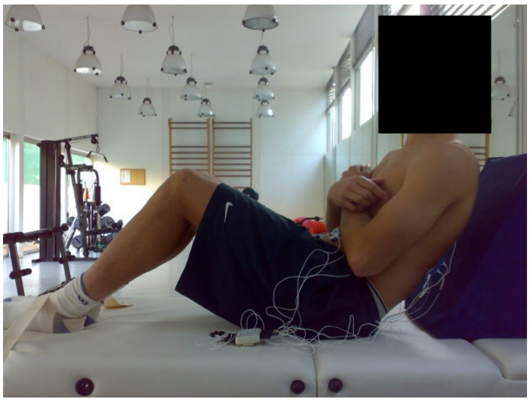

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Figure 1 - Flexor test.

The extensor (Biering-Sørensen) test was performed with the subjects lying in a prone position with the trunk over a table by the level of the anterior superior iliac spines. Fixation straps were positioned at the hips, knees and ankles (figure 2).

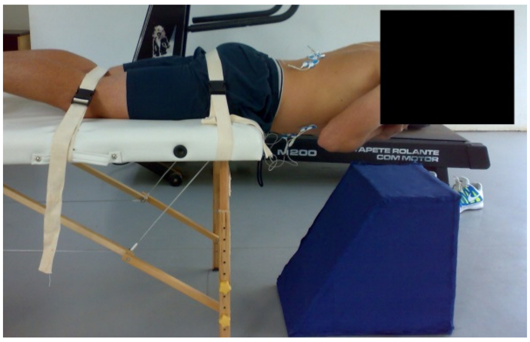

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Figure 2 - Extensor (Biering-Sørensen) test.

Left and right side bridges tests were performed with the subjects lying sideways supported by the forearm and feet, forming a straight line between the trunk and lower limbs (figure 3).

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Figure 3 - Side bridge test.

This protocol has been considered a safe, simple and cost-effective way of evaluating trunk endurance (Evans et al., 2007, 2005; Ito et al., 1996; McGill et al., 1999). To familiarize the subjects with the testing positions, they had the opportunity of experimenting them for a few seconds before the start of the tests. The order of the four tests was randomized for each subject, so as to eliminate a possible influence of the tests' order on the subjects' performance. 5 minutes of rest, measured with a stopwatch, were given between tests, as in the study of McGill et al., 1999. All subjects (or their legal tutors) gave their written consent for participation in the study. The study was approved by the Research Ethics Committee of the Faculty of Human Kinetics from the Technical University of Lisbon.

Data collection

LBP history was obtained through an adapted version of the Nordic Musculoskeletal Questionnaire (NMQ, original version by Kuorinka et al., 1987, Portuguese adaptation by Mesquita, Ribeiro, & Moreira, 2010, appendix 1) containing only the lumbar region section. Subjects answered three yes/no questions: 1) existence of lumbar symptoms (pain, ache, discomfort) over the last 12 months (LBP condition) or 2) over the last 7 days (LBP-7d condition); 3) being unable to train or play over the last 12 months because of these symptoms (LBP-TR condition). Participants who had lumbar complaints also signalled their intensity on a scale from 1 to 10. For the purpose of this study, LBP subjects will be considered those who answered the first question affirmatively.

Beginning and end of the recording was done with a keyboard trigger. Tests were considered as terminated when subjects could no longer hold the testing position.

EMG data was recorded during the tests from 4 muscle pairs bilaterally (RA, EO and two portions of ES: longuissimus thoracis (ES-L) and iliocostalis lumborum (ES-I)). These muscles were chosen because of their previous use in similar studies and importance in the execution of tennis strokes.

In order to decrease the impedance of the skin-sensor interface, subjects' skin was shaved and cleaned with alcohol before sensor placement. The electrodes were aligned with muscle fibre orientation with a centre-to-centre distance of 20mm. EMG analysis was only performed for data corresponding to the test directed at each muscle (eg. side bridge for the EO, Biering-Sørensen test for the ES-L and ES-I). Sensor placement was done according to the recommendations of the SENIAM project (Hermens et al., 1999) for both portions of the ES. Since no SENIAM recommendations were available for the abdominal muscles, placement for the RA and EO was done according to Ng et al., 2002 (figures 4 and 5)

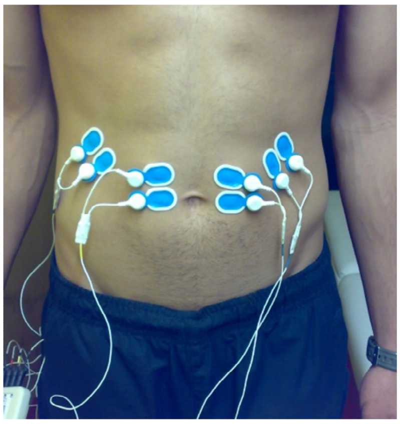

Figure 5 - Sensor placement (anterior).

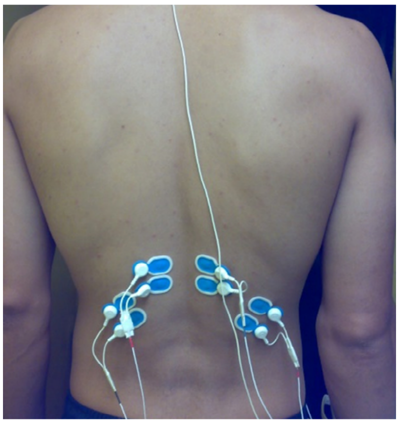

Figure 5 - Sensor placement (posterior).

Active Ag-AgCl pre-gelled electrodes were connected to a bioPLUX research 2010 system (PLUX, Lisbon, Portugal) with a common mode rejection ratio of 110dB, input impedance >100MΩ and a gain of 1000. The sampling rate was 1000Hz.

For left-handed subjects EMG data was transposed so that the right side data corresponded to the dominant side in all subjects. Figure 6 depicts an example of a set of raw EMG signals.

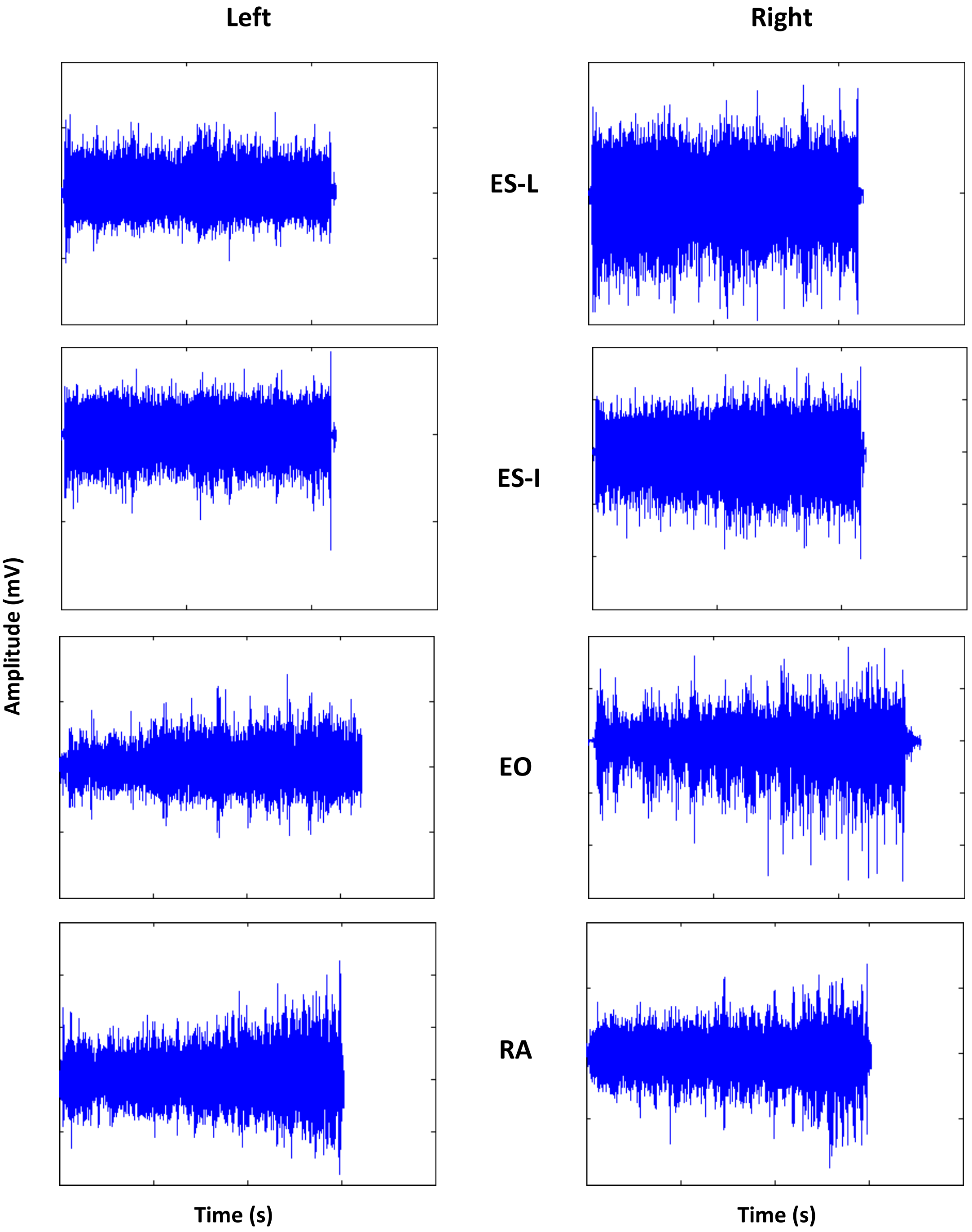

Figure 6 – Set of raw EMG signals. X and Y axes represent respectively time in seconds and amplitude values in mV.

Data processing

Endurance time was calculated through the division of the number of samples recorded by the sampling rate and rounded to the nearest second.

EMG raw data was processed using MATLAB (The Mathworks Inc., Natick, MS, USA) through a digital filter (10-490Hz). For amplitude processing, EMG data was full-wave rectified, smoothed using a 4th order 12Hz Butterworth filter and normalized to the mean amplitude value of the 3-6 second data interval. This normalization to the baseline value was performed so as to allow comparison between subjects. The first three seconds were ignored for this process in order to ensure a better signal stabilization and consequently a more reliable basis for normalization (Oddsson & De Luca, 2003). In order to account for the different endurance times between subjects, test duration was normalized to 100% and divided in 10th percentile intervals, as done by Olson, 2010 and Pereira, De Oliveira, & Nadal, 2011. Average EMG (avrEMG) and MF values were calculated for every tenth percentile, resulting in 11 avrEMG and MF values for each muscle. A graphical representation of this division is depicted in figure 7. The use of avrEMG and MF as a means of evaluation muscle activation and fatigue is widely present in literature (De Luca, 1993; Farina & Merletti, 2000; González-Izal, Malanda, Gorostiaga, & Izquierdo, 2012; C Larivière, Arsenault, Gravel, Gagnon, & Loisel, 2002; Ng, Richardson, & Jull, 1997; van Dieën, Oude Vrielink, & Toussaint, 1993). AvrEMG values were obtained by the following equation:

$$avrEMG = \frac{1}{N}\sum_{i=1}^{N} |x_i| \quad (1)$$

where N is the number of samples considered and x_i are the signal samples. avrEMG was determined through the mean value of 2000ms windows around each percentile.

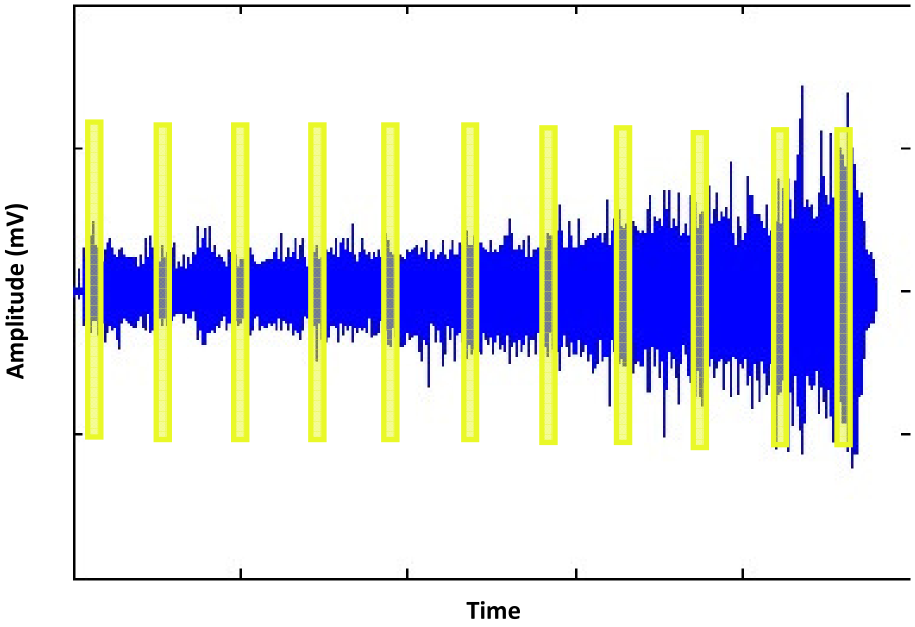

Figure 7 - Graphical representation of the EMG signal's division into percentiles. Yellow bars represent the 2000ms windows used to calculate the mean values. X and Y axes represent respectively time in seconds and amplitude values in mV. EMG signal obtained from a left external oblique.

Median frequency (MF) values were obtained by the following equation:

$$\int_0 f^{med} S_m(f)df = \int^{\infty} f^{med} S_m(f)df \quad (2)$$

where $S_m(f)$ is the frequency spectrum of the signal, $\int f^{\text{med}}$ is the MF of the signal and f is the frequency in Hz. MF values were determined using a Fast Fourier Transform (FFT) algorithm with 1000ms windows. The use of FFT in frequency processing of signals from isometric prolonged contractions has been corroborated by previous studies (Coorevits, Danneels, Cambier, Ramon, Druyts, Karlsson, et al., 2008; Coorevits, Danneels, Cambier, Ramon, Druyts, Karlsson, et al., 2008)

The total avrEMG was determined through the mean of the 11 calculated percentiles. MF slope (MFslope) was considered to be the value of the linear regression slope from the 11 MF values.

Four endurance time ratios (flexor/extensor, right/left extensor, left and right side bridge/extensor) were obtained by dividing the corresponding values of endurance times.

Ten total avrEMG ratios were also calculated. Right/left individual muscle ratios and the individual flexor/extensor ratios were obtained in the same way as endurance time ratios. Muscle groups ratios (flexors/extensors and left/right extensors) were obtained by dividing the average of all portions of the muscle groups (eg. average total avrEMG of the 2 right portions of ES/average avrEMG of the 2 left portions of ES). Average amplitude ratios of contralateral and antagonistic muscle pairs have been used in previous EMG studies (Larivière & Arsenault, 2008; Oddsson & De Luca, 2003; Olson, 2010; Renkawitz et al., 2006).

Side-to-side differences for each muscle pair were analysed in a similar way to Renkawitz et al., 2006. Thus, there was considered to be a side-to-side difference if the ratio between the dominant and nondominant portions was more than 30% deviated from 1.

Signals from six endurance tests (two from left side bridges, two from flexor tests, one from a Biering-Sørensen test and one from a right side bridge) were found to be damaged and were not considered for analysis.

Statistical analysis

Statistical analysis was performed using IBM© SPSS® Statistics for Windows 20.0 (IBM© Corp. Armonk, New York). Normality of all data was assessed using the Shapiro-Wilk test. Endurance time and ratio differences between subjects were tested through independent samples t-tests or independent samples Mann-Whitney tests, according to the normality of each variable. Changes in avrEMG and MF values across the 11 percentiles were assessed using a Friedman repeated measures test. Differences in total avrEMG and MF slopes between subjects with and without LBP was done using independent samples t-tests or independent samples Mann-Whitney tests, according to the normality of each variable. Paired samples testing was done using t-tests or the Wilcoxon signed ranks test, according to the normality of each variable. The independence of variables in the EMG side-to-side analysis was performed using chi-square tests. Correlations were calculated using Pearson’s r coefficient. A significance level of 0,05 was used for all tests.

RESULTS

NMQ data

Regarding the NMQ data, 20 subjects (57%) indicated having LBP symptoms over the last 12 months. Mean symptom intensity was 5,2±1,99 with values ranging from 3 to 9. Of these 20 subjects, 8 (40%) reported having symptoms over the last 7 days and 7 (35%) indicated having been unable to train or play over the last 12 months because of these symptoms. The percentages of subjects with LBP in the last 7 days and unable to train or play due to LBP in the last 12 months in the whole sample were, respectively, 23% and 20%.

Endurance time data

Subjects without LBP showed increased endurance time for all tests. However, these differences were significant only for the flexor (p=0,004) and right side bridge (p=0,043) tests. Healthy subjects held the testing position, on average, 121 seconds longer for the flexor test and 22 seconds longer for the right side bridge test. The endurance time ratio analysis produced a significant difference for the flexor/extensor ratio between healthy and LBP subjects (1,78 vs. 1,17, p=0,010). Detailed results for endurance time and ratio data between subjects with and without LBP can be seen on tables 2 and 3.

Table 2 - Endurance time (in seconds) between subjects with and without LBP. Significant values denoted in bold.

Test	LBP	Mean±SD	P
Flexor test	No	264,27±132,58	**0,004**
	Yes	143,15±45,87	
Extensor test	No	154,60±61,61	0,136
	Yes	127,40±32,76	
Left side bridge	No	92,07±24,59	0,071
	Yes	75,65±26,62	
Right side bridge	No	99,27±37,07	**0,043**
	Yes	77,70±23,49	

Table 3 - Endurance time ratios tests between subjects with and without LBP. Significant values denoted in bold.

Ratio	LBP	Mean±SD	p
Flexor/extensor	No	1,78±0,76	**0,010**
	Yes	1,17±0,39	
Right/left side bridge	No	1,06±0,17	0,755
	Yes	1,08±0,24	
Right side bridge/extensor	No	0,69±0,23	0,735
	Yes	0,66±0,25	
Left side bridge/extensor	No	0,66±0,26	0,564
	Yes	0,61±0,30	

The endurance time and ratio analysis for the LBP-7d and LBP-TR conditions produced no significant differences for all parameters. Full results can be seen on tables 14 to 17, appendix 5.

Paired samples testing for the right-left side bridge and flexor-extensor endurance time produced a significant (p<0,0005) difference between the flexor and extensor endurance time in healthy subjects. All the other pairs produced no significant differences. Results are visible on table 4.

Table 4 - Paired samples tests for endurance time data. Significant values denoted in bold.

Comparison	LBP	p	LBP-7d	p	LBP-TR	p
Right-left side bridge	No	0,181	No	0,966	No	0,843
	Yes	0,358	Yes	0,086	Yes	0,126
Flexor-extensor	No	**<0,0005**	No	0,226	No	0,111
	Yes	0,180	Yes	0,656	Yes	0,826

Correlation testing between endurance time and ratio results and complaints of LBP yielded three significant correlations, all of which were negative. The flexor endurance time (r=-0,533; p=0,001), right side bridge time (r=-0,344; p=0,043) and flexor/extensor ratio (r=-0,476; p=0,004) were all significantly correlated with LBP status. These results are detailed in figures 8 to 10.

Regarding the correlation testing between endurance parameters and symptom intensity, no significant correlation was found (table 5).

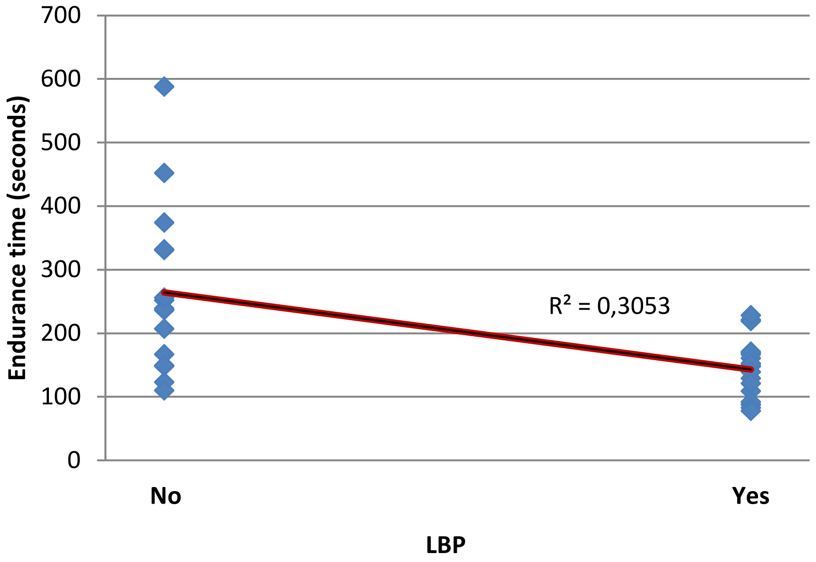

Figure 8 - Correlation between flexor endurance time and LBP status.

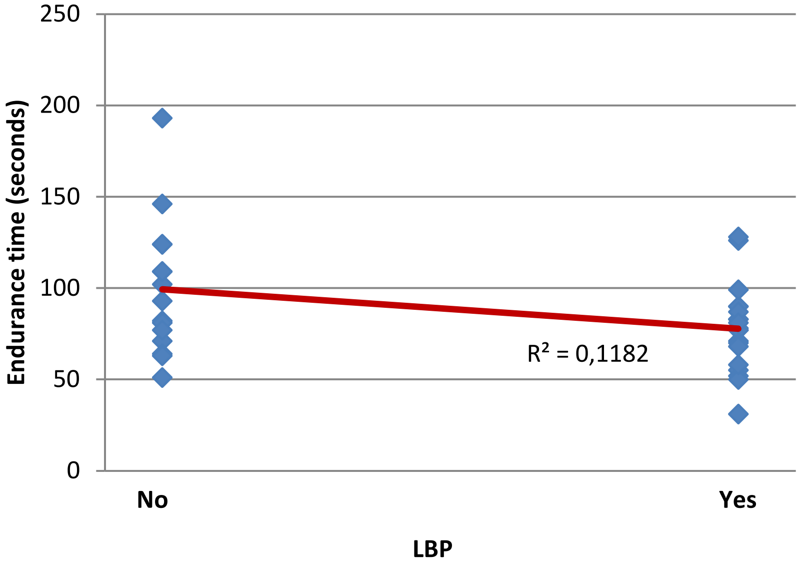

Figure 9 - Correlation between right side bridge endurance time and LBP status.

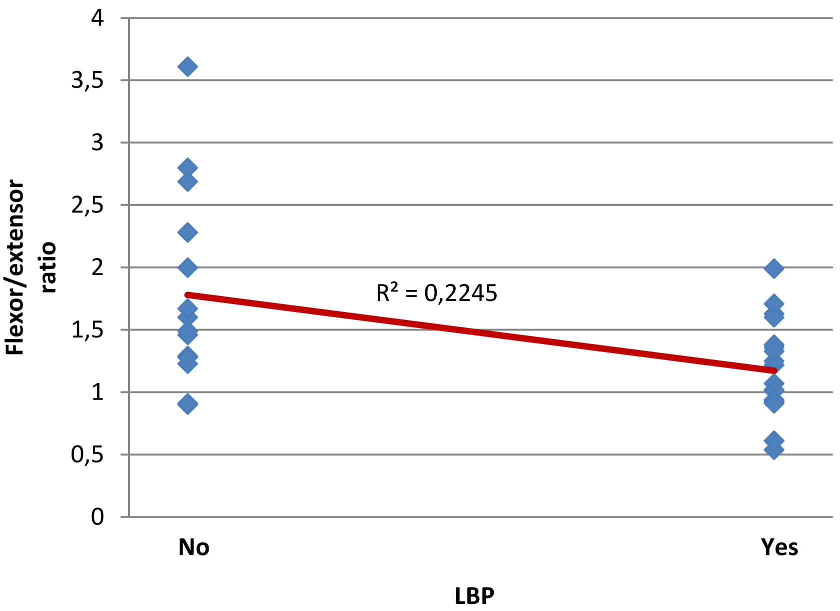

Figure 10 - Correlation between flexor/extensor endurance ratio and LBP status.

Table 5 - Correlations between LBP status, pain intensity and endurance parameters. Significant values denoted in bold.

	Parameter	Pearson's r	r^2	p
LBP	**Flexor test**	**-0,533**	0,284	**0,001**
	Extensor test	-0,282	0,080	0,101
	Left side bridge	-0,309	0,095	0,071
	Right side bridge	**-0,344**	0,118	**0,043**
	Flexor/extensor	**-0,476**	0,227	**0,004**
	Right/left side bridge	0,043	0,002	0,807
	Right side bridge/extensor	0,059	0,003	0,735
	Left side bridge/extensor	-0,084	0,007	0,630
Intensity	Flexor test	-0,312	0,097	0,181
	Extensor test	-0,095	0,009	0,690
	Left side bridge	-0,184	0,034	0,436
	Right side bridge	-0,021	0,000	0,929
	Flexor/extensor	-0,277	0,077	0,237
	Right/left side bridge	0,078	0,006	0,743
	Right side bridge/extensor	-0,155	0,024	0,515
	Left side bridge/extensor	-0,106	0,011	0,656

EMG data

For healthy subjects, avrEMG significantly increased over the course of the endurance tests on the left and right ES-I (p=0,018 and p=0,024), and for both sides of the RA and EO (both with p<0,0005). Subjects with LBP showed an increase in avrEMG for both sides of the RA and EO (both with p<0,0005) and right ES-L (p=0,002).

MF significantly decreased during the execution of the tests for all muscles in all subjects, with a p<0,0005 for all the tests except that of the left RA in healthy subjects (p=0,001). Detailed results are presented on table 6. A graphical representation of these changes can be seen on figure 11.

Table 6 - Friedman repeated measures test for avrEMG and MF changes in individual muscles over the course of the endurance tests. Significant values denoted in bold.

	Muscle	LBP	p		Muscle	LBP	p
avrEMG	Left ES-I	No	**0,018**	MF	Left ES-I	No	**<0,0005**
		Yes	0,795			Yes	**<0,0005**
	Left ES-L	No	0,119		Left ES-L	No	**<0,0005**
		Yes	0,079			Yes	**<0,0005**
	Right RA	No	**<0,0005**		Right RA	No	**<0,0005**
		Yes	**<0,0005**			Yes	**<0,0005**
	Right EO	No	**<0,0005**		Right EO	No	**<0,0005**
		Yes	**<0,0005**			Yes	**<0,0005**
	Right ES-I	No	**0,024**		Right ES-I	On	**<0,0005**
		Yes	0,430			Yes	**<0,0005**
	Right ES-L	No	0,382		Right ES-L	No	**<0,0005**
		Yes	**0,002**			Yes	**<0,0005**
	Left RA	No	**<0,0005**		Left RA	No	**0,001**
		Yes	**<0,0005**			Yes	**<0,0005**
	Left EO	No	**<0,0005**		Left EO	No	**<0,0005**
		Yes	**<0,0005**			Yes	**<0,0005**

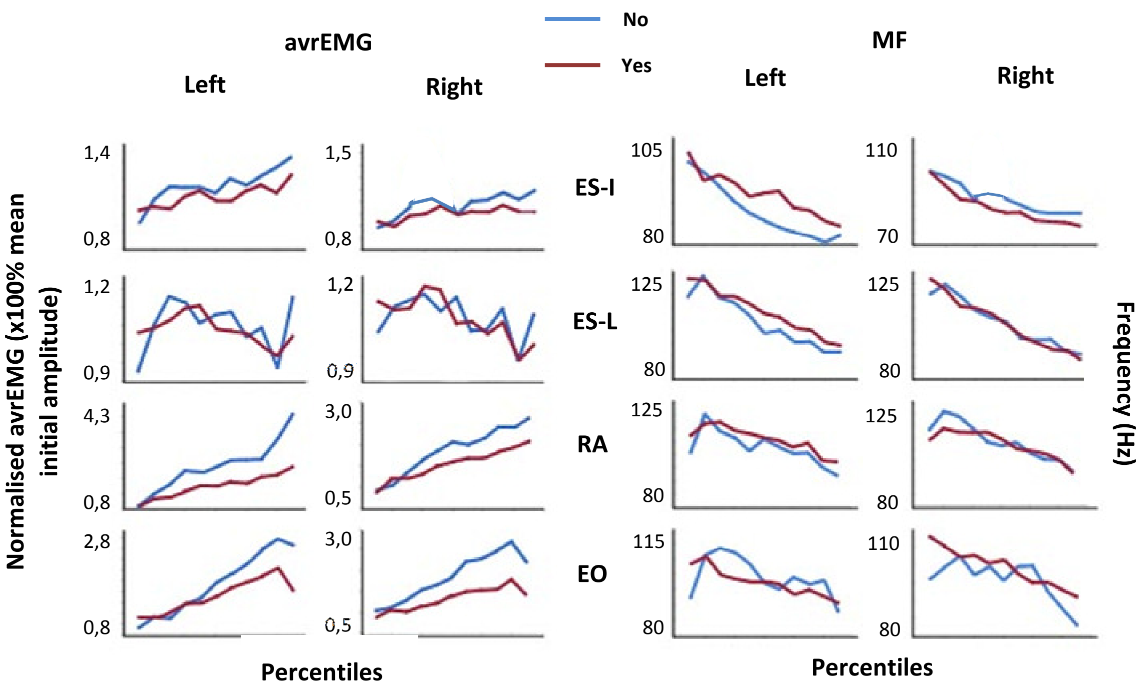

Figure 11 - Graphic representation of changes in avrEMG and MF during the endurance tests for subjects with (red) and without (blue) LBP. X axes represent the percentiles and Y axes represent the normalized avrEMG and MF (Hz).

Repeated measures tests for changes in avrEMG ratios during the tests revealed significant increases for all RA/ES ratios in all LBP conditions (12-month prevalence, 7-day prevalence and unable to train or play during last 12 months, table 7).

Table 7 - EMG ratios Friedman repeated measures test results. Significant values denoted in bold.

	Ratio	LBP	p	LBP-7d	p	LBP-TR	p
avrEMG	L RA/ES-I	No	**<0,0005**	No	**<0,005**	No	**<0,0005**
		Yes	**<0,0005**	Yes	**<0,005**	Yes	**<0,0005**
	L RA/ES-L	No	**0,016**	No	**<0,005**	No	**<0,0005**
		Yes	**<0,0005**	Yes	**<0,005**	Yes	**0,001**
	R RA/ES-I	No	**0,003**	No	**<0,005**	No	**<0,0005**
		Yes	**<0,0005**	Yes	**<0,005**	Yes	**0,004**
	R RA/ES-L	No	**0,015**	No	**0,002**	No	**<0,0005**
		Yes	**<0,0005**	Yes	**<0,0005**	Yes	0,057
	R/L RA	No	0,174	No	0,741	No	0,980
		Yes	0,884	Yes	0,908	Yes	0,139
	R/L EO	No	0,680	No	0,638	No	0,663
		Yes	0,887	Yes	0,948	Yes	0,636
	R/L ES-L	No	0,561	No	0,111	No	0,410
		Yes	0,297	Yes	0,606	Yes	0,320
	R/L ES-I	No	0,932	No	0,381	No	0,481
		Yes	0,316	Yes	0,591	Yes	0,188
	Flexor/extensor	No	**<0,0005**	No	**<0,0005**	No	**<0,0005**
		Yes	**<0,0005**	Yes	**<0,0005**	Yes	**0,003**
	Right/left extensor	No	0,609	No	0,375	No	0,835
		Yes	0,796	Yes	0,843	Yes	0,372

Comparing the avrEMG and MF slope values of individual muscles between individuals with and without symptoms revealed that only the avrEMG of the right EO was significantly different (2,00 vs. 1,39; p=0,002, table 8).

As for the avrEMG ratios comparison between these subjects, it was found that the right/left EO ratio was significantly higher for the healthy subjects (1,35 vs. 0,99; p=0,027). None of the other ratios produced significant differences. The detailed results can be seen on table 9.

Table 8 - avrEMG and MFslope comparison between LBP and no-LBP subjects. Significant values denoted in bold.

	Muscle	N	LBP	Mean±SD	p
avrEMG	Left ES-I	14	No	1,18±0,18	0,460
		20	Yes	1,12±0,24	
	Left ES-L	14	No	1,06±0,17	0,856
		20	Yes	1,05±0,13	
	Right RA	15	No	2,01±1,24	0,255
		18	Yes	1,61±0,49	
	Right EO	14	No	2,00±0,65	**0,002**
		20	Yes	1,39±0,44	
	Right ES-I	14	No	1,28±0,40	0,172
		20	Yes	1,11±0,23	
	Right ES-L	14	No	1,06±0,15	0,726
		20	Yes	1,04±0,15	
	Left RA	15	No	2,36±1,75	0,550
		18	Yes	1,60±0,50	
	Left EO	14	No	1,88±0,83	0,686
		19	Yes	1,60±0,40	
MFslope	Left ES-I	14	No	-0,18±0,14	0,454
		20	Yes	-0,14±0,15	
	Left ES-L	15	No	-0,24±0,18	0,299
		20	Yes	-0,30±0,16	
	Right RA	15	No	-0,17±0,21	0,377
		20	Yes	-0,32±0,49	
	Right EO	15	No	-0,12±0,23	0,748
		20	Yes	-0,17±0,22	
	Right ES-I	15	No	-0,14±0,11	0,570
		20	Yes	-0,18±0,15	
	Right ES-L	14	No	-0,24±0,16	0,073
		19	Yes	-0,34±0,18	
	Left RA	15	No	-0,14±0,19	0,321
		20	Yes	-0,24±0,32	
	Left EO	14	No	-0,11±-0,18	0,864
		19	Yes	-0,14±0,19	

Table 9 - avrEMG ratios comparison between LBP and no-LBP subjects. Significant values denoted in bold.

	Ratio	N	LBP	Mean±SD	p
avrEMG	L RA/ES-I	14	No	2,28±1,80	0,536
		18	Yes	1,63±0,69	
	L RA/ES-L	14	No	2,00±1,69	0,925
		18	Yes	1,61±0,81	
	R RA/ES-I	14	No	1,91±1,31	0,925
		18	Yes	1,66±0,74	
	R RA/ES-L	14	No	1,59±0,94	0,808
		18	Yes	1,55±0,72	
	R/L RA	15	No	1,13±0,94	0,325
		18	Yes	1,02±0,18	
	R/L EO	13	No	1,35±0,57	**0,027**
		19	Yes	0,99±0,33	
	R/L ES-L	14	No	1,01±0,14	0,500
		20	Yes	1,00±0,10	
	R/L ES-I	14	No	1,09±0,22	0,522
		20	Yes	1,03±0,16	
	Flexor/extensor	14	No	1,85±1,16	0,639
		18	Yes	1,58±0,66	
	Right/left extensor	14	No	1,04±0,14	0,470
		20	Yes	1,01±0,12	

Side-to side analysis revealed that the proportion of subjects with differences for the left-right RA pair was associated with LBP status. 53% of healthy subjects showed avrEMG differences larger than 30%. This percentage was only 17% for the subjects with LBP. Chi-square testing for this association produced a p of 0,035. None of the other muscle pairs produced a significant association (table 10).

Table 10 - Side-to-side differences for subjects with and without LBP. Significant values denoted in bold.

LBP	**Left-right ES-I**		**Left-right ES-L**		**Left-right RA**		**Left-Right EO**	
	Diff	**No Diff**	**Diff**	**No Diff**	**Diff**	**No Diff**	**Diff**	**No Diff**
No	2	12	1	14	8	7	4	9
Yes	1	19	0	20	3	15	7	12
Chi-square p	0,374		0,429		**0,035**		0,767	

Changes in avrEMG and MF for subjects with and without LBP on the last 7 days revealed that healthy subjects had a significant increase in avrEMG for both sides of the ES-I (left: p=0,028; right: 0,027), RA and EO (all with p<0,0005). MF decreased significantly for all muscles with a p<0,0005, except for the EO (p=0,006) (table 11).

Subjects with LBP on the last 7 days showed an increase in avrEMG for both sides of the ES-L (left: p=0,043; right: p=0,005), RA (left: p=0,001; right: p=0,002) and EO (p<0,0005). A graphical representation of these changes can be seen on figure 12.

Table 11 - Friedman repeated measures tests for changes in avrEMG and MF during the endurance tests for subjects with and without LBP on the last 7 days.

	Muscle	**LBP**	**p**		**Muscle**	**LBP**	**P**
avrEMG	Left ES-I	No	**0,028**	**MF**	Left ES-I	No	**<0,0005**
		Yes	0,247			Yes	0,263
	Left ES-L	No	0,438		Left ES-L	No	**<0,0005**
		Yes	**0,043**			Yes	**<0,0005**
	Right RA	No	**<0,0005**		Right RA	No	**<0,0005**
		Yes	**0,002**			Yes	0,542
	Right EO	No	**<0,0005**		Right EO	No	**0,006**
		Yes	**<0,0005**			Yes	**<0,0005**
	Right ES-I	No	**0,027**		Right ES-I	No	**<0,0005**
		Yes	0,056			Yes	**0,002**
	Right ES-L	No	0,302		Right ES-L	No	**<0,0005**
		Yes	**0,005**			Yes	**<0,0005**
	Left RA	No	**<0,0005**		Left RA	No	**<0,0005**
		Yes	**0,001**			Yes	0,193
	Left EO	No	**<0,0005**		Left EO	No	**0,006**
		Yes	**<0,0005**			Yes	**0,007**

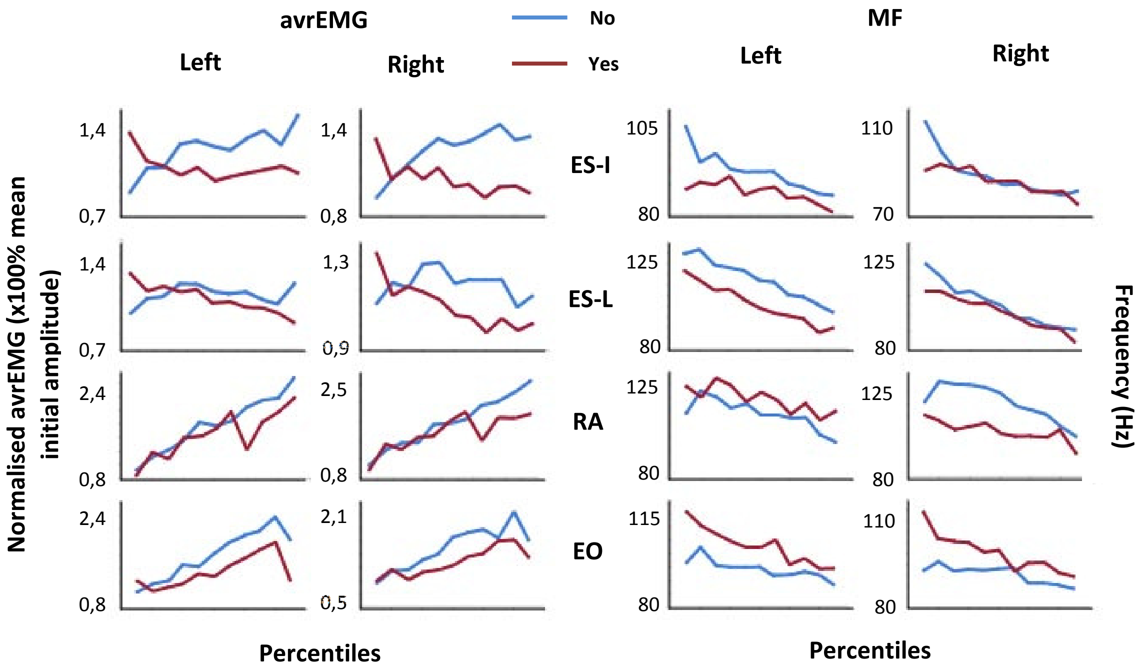

Figure 12 - Graphic representation of changes in avrEMG and MF during the endurance tests for subjects with (red) and without (blue) LBP on the last 7 days. X axes represent the percentiles and Y axes represent, respectively, normalized avrEMG and MF (Hz).

Testing the differences of avrEMG and MFslope values between subjects with and without LBP complaints over the last 7 days produced no significant discrepancies (table 18, appendix 5). Similarly, the avrEMG ratios also did not show such differences on these subjects (table 19, appendix 5). Side-to-side differences for each muscle pair did not reveal any significant associations (table 20, appendix 5).

The Friedman repeated measures tests for avrEMG and MF changes showed that subjects who were not prevented from training or playing due to LBP had a significant bilateral avrEMG increase on the RA and EO (all with p<0,0005). These subjects also had a significant decrease in MF on all muscles analysed, all with p<0,0005 except the right EO (p=0,001).

Subjects who did not train or play because of LBP showed a significant increase in avrEMG on the left (p=0,006) and right (p=0,018) ES-L, as well as on both sides for the RA (left: p=0,001; right: p=0,016) and EO (both with p<0,0005). MF decreased significantly on both sides of the ES-L (p<0,005), right ES-I (p=0,033) and right EO (p=0,025). The complete results can be seen on table 12. A graphical representation of these changes can be seen on figure 13.

Table 12 - Friedman repeated measures tests of avrEMG and MF values during the endurance tests for subjects with and without LBP preventing them from training on the last 12 months. Significant values denoted in bold.

	Muscle	LBP	p		Muscle	LBP	p
avrEMG	Left ES-I	No	0,066	**MF**	Left ES-I	No	**<0,0005**
		Yes	0,185			Yes	0,272
	Left ES-L	No	0,723		Left ES-L	No	**<0,0005**
		Yes	**0,006**			Yes	**<0,0005**
	Right RA	No	**<0,0005**		Right RA	No	**<0,0005**
		Yes	**0,016**			Yes	0,085
	Right EO	No	**<0,0005**		Right EO	No	**0,001**
		Yes				Yes	**0,025**
	Right ES-I	No	0,195		Right ES-I	No	**<0,0005**
		Yes	0,139			Yes	**0,033**
	Right ES-L	No	0,153		Right ES-L	No	**<0,0005**
		Yes	**0,018**			Yes	**<0,0005**
	Left RA	No	**<0,0005**		Left RA	No	**<0,0005**
		Yes	**0,001**			Yes	0,313
	Left EO	No	**<0,0005**		Left EO	No	**<0,0005**
		Yes	**<0,0005**			Yes	0,118

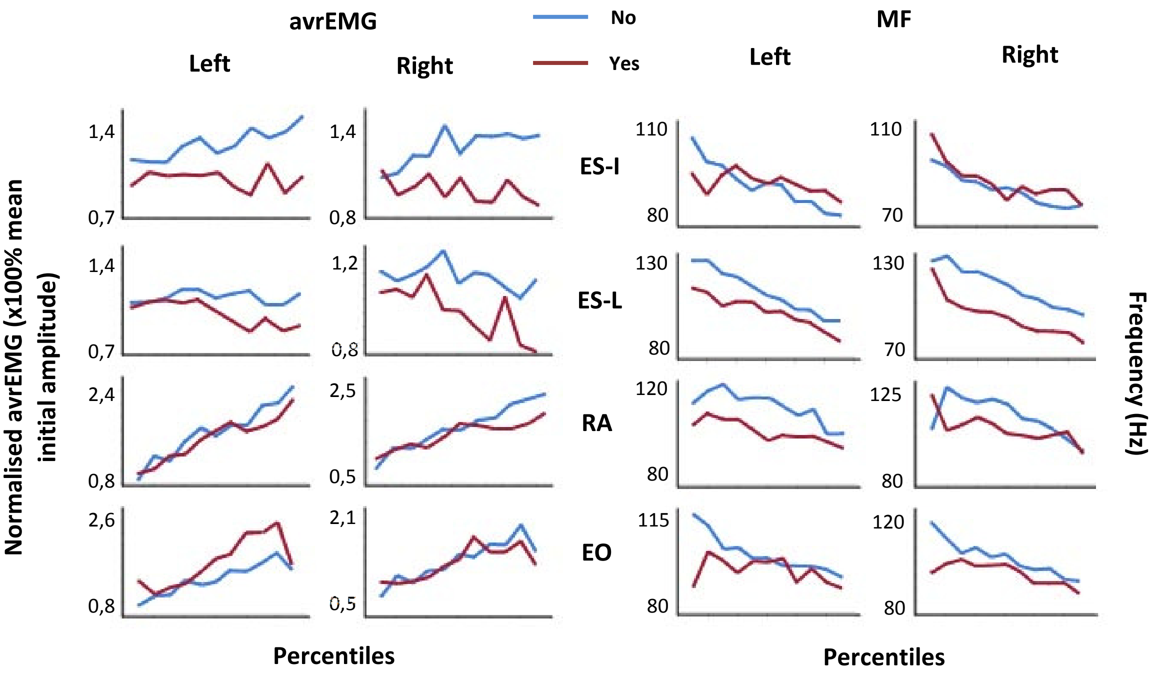

Figure 13 - Graphic representation of changes in avrEMG and MF during the endurance tests for subjects with (red) and without (blue) LBP preventing them from training or playing on the last 12 months. X axes represent the percentiles and Y axes represent, respectively, normalized avrEMG and MF (Hz).

Subjects that reported being unable to train or play tennis over the last 12 months showed a significantly higher avrEMG of the right ES-I (1,19 vs. 0,96; p=0,024), as well as a steeper negative MFslope (-0,19 vs. -0,05) of the left portion of the same muscle (p=0,044). These results are detailed on table 13. Both the avrEMG ratios and the side-to-side differences between muscle pairs did not reveal any significant results (tables 21 and 22, appendix 5).

Table 13 - avrEMG and MFslope comparison between subjects with LBP preventing them from training or playing on the last 12 months. Significant values denoted in bold.

	Muscle	N	LBP	Mean±SD	P
avrEMG	Left ES-I	13	No	1,19±*0,21*	0,075
		7	Yes	0,99±*0,25*	
	Left ES-L	13	No	1,09±*0,13*	0,074
		7	Yes	0,98±*0,10*	
	Right RA	11	No	1,67±*0,49*	0,573
		7	Yes	1,52±*0,53*	
	Right EO	13	No	1,41±*0,54*	0,737
		7	Yes	1,35±*0,21*	
	Right ES-I	13	No	1,19±*0,20*	**0,024**
		7	Yes	0,96±*0,20*	
	Right ES-L	13	No	1,08±*0,14*	0,085
		7	Yes	0,96±*0,14*	
	Left RA	11	No	1,64±*0,49*	0,677
		7	Yes	1,53±*0,54*	
	Left EO	12	No	1,48±*0,37*	0,261
		7	Yes	1,78±*0,39*	
MFslope	**Left ES-I**	13	No	-0,19±*0,15*	**0,044**
		7	Yes	-0,05±*0,09*	
	Left ES-L	13	No	-0,30±*0,15*	0,907
		7	Yes	-0,30±*0,18*	
	Right RA	11	No	-0,25±*0,29*	0,360
		7	Yes	-0,46±*0,75*	
	Right EO	13	No	-0,11±*0,17*	0,110
		7	Yes	-0,28±*0,27*	
	Right ES-I	13	No	-0,15±*0,05*	0,536
		7	Yes	-0,22±*0,25*	
	Right ES-L	13	No	-0,32±*0,13*	0,369
		7	Yes	-0,41±*0,25*	
	Left RA	11	No	-0,25±*0,33*	0,740
		7	Yes	-0,20±*0,32*	
	Left EO	12	No	-0,10±*0,18*	0,246
		7	Yes	-0,21±*0,20*	

Of all average avrEMG and MF slope parameters, only the average avrEMG of the right EO was significantly correlated (r=-0,497; p=0,002) with having LBP (table 23, appendix 5). The correspondent avrEMG ratio correlation testing revealed that the ratio between right and left EO was significantly and negatively correlated with having LBP (r=-0,382; p=0,031, table 23, appendix 5). Testing the correlation between the avrEMG and MFslope values of individual muscles and symptom intensity produced a significant correlation for the MF slope of the left ES-I (r=0,533; p=0,016) and right EO (r=-0,522; p=0,018). Symptom intensity correlations can be seen on table 24, appendix 5. The correspondent analysis for the avrEMG ratios produced a significant negative correlation for the right/left EO ratio (r=0,382; p=0,031, table 25, appendix 5). A graphical representation of these correlations can be seen on figures 14 to 16.

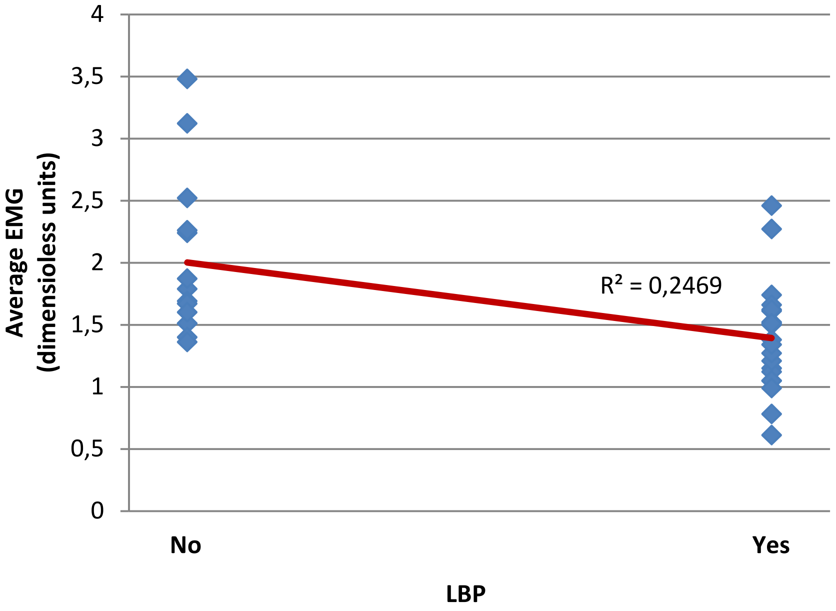

Figure 14 - Correlation between the avrEMG of the right EO and LBP status.

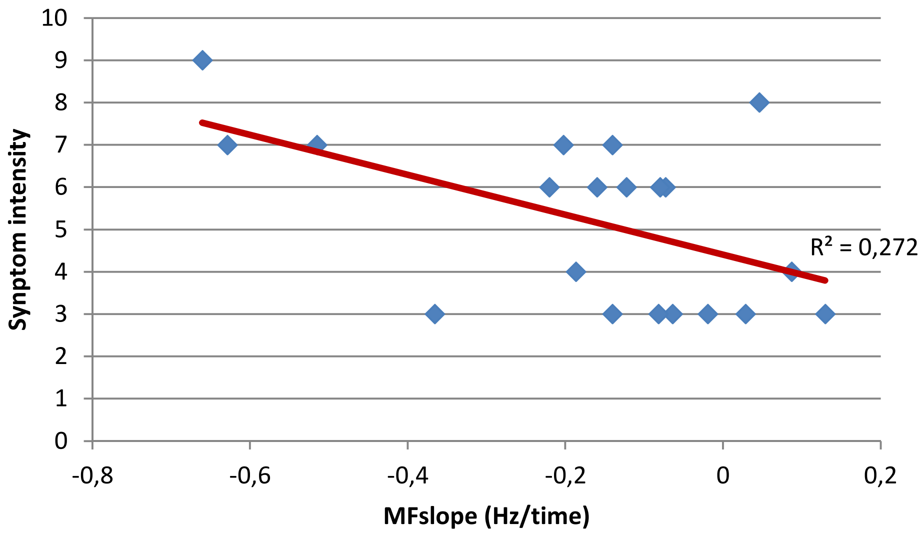

Figure 15 - Correlation between symptom intensity and MFslope of the right EO.

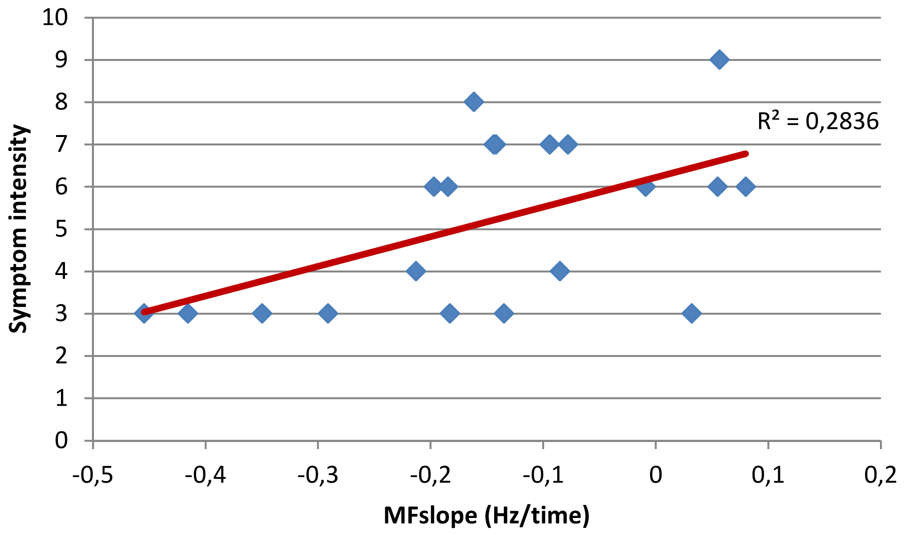

Figure 16 - Correlation between symptom intensity and MFslope of the left ES-I.

DISCUSSION

Our sample of 35 competitive tennis players presented a 57% 12-month prevalence of lumbar symptoms (20 subjects), which is a higher value than usually reported by most epidemiological studies in tennis (Ellenbecker et al., 2009; Hjelm et al., 2012;

Kibler & Safran, 2000). This is probably due to the large retrospective period of the NMQ (12 months). However, it is similar to the value found by Renkawitz, Boluki, & Grifka, 2006. Regardless of the previous studies' results, it shows that low back complaints can be quite common in tennis players. Moreover, they correspond to the estimate of Kibler & Safran, 2005 that half of all tennis players present LBP symptoms lasting at least for a week. The percentage of players being unable to train or play because of these complaints over the same period is somewhat lower than the value presented by Kibler & Safran, 2000. However, 20% of tennis players in our sample reported such complaints, which is still a relevant figure.

Moving to the endurance time analysis, it was determined that although healthy subjects did show greater extensor endurance time, this difference was not significant. Thus, results from this study do not support the results from studies which show subjects with LBP have less extensor endurance (Arab et al., 2007; Biering-Sørensen, 1984; Demoulin et al., 2006; Ito et al., 1996; Luoto, Heliijvaara, Hurri, & Alaranta, 1995). The values found are more in accordance with the results of Evans et al., 2005 and Pitcher et al., 2007 which show no significant extensor endurance between healthy and LBP subjects. The inexistence of an association between extensor endurance time and LBP in this study is also supported by the absence of a significant correlation. The absolute value of extensor endurance time found in this study fits inside the scope of normative values found in two revisions and an individual sample study of healthy and LBP subjects (Coleman et al., 2011; Demoulin et al., 2006; Moreau et al., 2001). These were slightly higher than those of Pitcher et al., 2007 and Adedoyin, Mbada, Farotimi, Johnson, & Emechete, 2011 and lower than the values found by McGill et al., 1999. All in all, tennis players from this sample not only showed no significant difference in their extensor endurance between healthy and symptomatic subjects but also had values comparable to those of the general population.

On the other hand, flexor endurance time was significantly higher in healthy subjects. These results add to the isokinetic strength testing data produced by Roetert et al., 1996 that found, in tennis players, greater flexion strength and flexion/extension strength ratios between 1,02 and 1,22. The average endurance ratio in this study showed an even higher value of 1,78 for healthy subjects. This value is superior to that reported by Chan, 2005 in rowers (1,55). LBP subjects presented a ratio of 1,17, which is similar to the strength ratio found by the previously mentioned authors. Nevertheless, both these endurance ratios are higher than those found in the healthy general population, which are below 1 (McGill et al., 1999). The increase in the flexor/extensor endurance ratio was thus driven by the increase in flexor endurance and not by a reduction in extensor endurance.

The greater flexor endurance also does not support the results found by Swärd et al., 1990, which found, for tennis players, a greater isometric MVC in extension than in flexion. Comparing the flexor endurance time with that found by McGill et al., 1999, the healthy subjects had a longer endurance time, while LBP subjects showed similar values to those of the healthy general population. The values of all subjects are comparable to those of Evans et al., 2005 in golfers and lower than those of Evans et al., 2007 in an athletic population. Both the flexor endurance time and flexor/extensor ratio were significantly correlated with LBP status, which indicates that in this sample of tennis players, greater flexor endurance was found to be a protective factor. Possible reasons for this fact will be presented later in the discussion.

Side bridge testing produced a significant difference for the right (dominant) side bridge according to LBP status, with healthy subjects presenting a greater endurance time. This value was also significantly correlated with LBP status. On the contrary, the side bridge ratio or testing the differences between the left and right tests did not produce significant discrepancies. These endurance parameters correspond to the range of isokinetic trunk rotation strength ratios found by Ellenbecker & Roetert, 2004 and are similar to endurance times found in the sample of athletes in Evans et al., 2007. Side bridge endurance times for healthy subjects are also comparable to the normative values presented by McGill et al., 1999, while the values of LBP subjects in the present study are slightly lower. Both side bridge/extensor ratios showed no differences between subjects. The average values found were higher than those of McGill et al., 1999.

No significant endurance time differences or interactions were found for the tests in the 7-day LBP or in the being unable to train or play conditions. This fact indicates that changes in endurance time are more decisive for differentiating healthy and non-healthy subjects than the differences in LBP characteristics (eg. acute vs. chronic, impact on activity).

As a whole, endurance time results indicate that, in this sample of tennis players, greater endurance of the trunk flexor (peripheral) muscles is a protective factor for LBP and that the endurance of paraspinal (local) muscles endurance is not relevant for the occurrence of LBP.

Looking more closely at the EMG data, repeated measures testing for the evolution of avrEMG and MF values during the execution of the tests revealed a relatively well defined pattern regardless of the LBP condition. In general, all subjects showed a significant increase in avrEMG and a corresponding decrease in MF for all abdominal muscles. The exceptions to this were the subjects who had had LBP in the last 7 days and those unable to train or play in the last 12 months because of LBP, who did not show a significant increase in avrEMG for both sides of the RA. It would seem, though, that an increase in RA activation during the flexor endurance test is more relevant for avoiding acute and activity-impairing LBP.

The correspondent data for the extensor muscles showed that all subjects had a significant decrease in MF for both portions of the ES, but there were important differences in the avrEMG results. Healthy subjects and those without LBP in the last 7 days had a bilateral significant avrEMG increase, respectively, for the ES-L and ES-I. Subjects who had LBP but were not unable to train or play did not show any change in avrEMG. On the contrary, subjects who answered affirmatively any of the LBP questions showed either a unilateral or bilateral decrease in avrEMG during the endurance tests. This indicates that symptomatic subjects reduced their ES activation while still holding the position and reaching a fatigue level similar to healthy subjects, as shown by the similar MF slope. This may be due to load sharing between synergistic muscles in order to avoid a painful contraction of the ES (Dario Farina, Gazzoni, & Merletti, 2003; Kankaanpei et al., 1998; van Dieën, Selen, & Cholewicki, 2003). Cole &

Grimshaw, 2008b also found reduced ES activity during the golf swing in subjects with LBP. These authors hypothesized this finding could be due to either reduced trunk stability or an adaptation of these subjects in order to avoid a painful contraction during movement. Since all the subjects in the present study had similar fatigability but lower levels of activation, it would seem that the current findings support the latter hypothesis.

Repeated measures testing for the evolution of avrEMG ratios showed that all but one flexor/extensor ratio increased significantly for all subjects in all conditions. This shows that despite the increasing differences in activation of the flexor and extensor muscles along the corresponding tests, this was a fact for both healthy and symptomatic subjects. Since there was also an absence of a significant correlation of these ratios with both LBP status and symptom intensity, it would seem that these differences in flexor and extensor activation amplitude during the correspondent test are not a factor in the aetiology of LBP in tennis players.

Comparison of individual muscles' average avrEMG and MF slope between subjects yielded significant data only for the average avrEMG of the right (dominant) EO, which was found to be significantly higher in healthy subjects. It was also the only EMG parameter of individual muscles found to be significantly correlated with having LBP. Cole & Grimshaw, 2008b also found increased activity of the EO muscles during the golf swing in healthy subjects compared to those with LBP. Contrary to the flexor/extensor ratios, the right/left EO avrEMG ratio was significantly higher in healthy subjects, mostly due to the increase in right EO average avrEMG, while subjects with LBP had an average ratio very close to 1, which is a value similar to the endurance time ratio found in healthy subjects in the general adult population (McGill et al., 1999). The increased average avrEMG of the right EO and greater right/left average avrEMG ratio in healthy subjects was accompanied, as previously discussed, by a greater endurance time of the right side bridge. Evans et al., 2005 found that elite young golfers with a left side bridge endurance deficit were more likely to report LBP episodes. Like in the golf swing of right handed players, the right EO is mostly active during the acceleration phases of the serve and forehand (Knudson & Blackwell, 2000) in tennis. Healthy subjects showed not only greater right side bridge endurance but also increased right EO avrEMG. Together, this could mean that because these subjects can perform correct stroke mechanics (with a greater activation level) for longer periods (because of greater endurance) of training or playing, they are at a reduced risk of LBP occurrence due to lack of proper motor patterns or trunk stability.

Changes in EMG parameters during the endurance tests collectively indicate that differences in fatigability (as evaluated by the MF slope) of trunk extensor, flexor and rotator muscles were not significant for the occurrence of LBP in these tennis players; instead, there were some differences in the extensor activation amplitude. This may indicate that the extensor pattern of activation may be more important than the fatigability of these muscles. Thus, although the decrease in MF is consistent with data from several other studies of isometric trunk extension (Coorevits, Danneels, Cambier, Ramon, & Vanderstraeten, 2008; De Luca, 1993; Ng et al., 1997; Pitcher et al., 2007; Roy et al., 1990; Sung et al., 2009), these showed no relation to LBP complaints in these tennis players.

Side-to-side asymmetries revealed that only the avrEMG differences between the left and right portions of the RA were significant for the LBP status. Significantly more healthy subjects (53%) than LBP subjects (17%), as determined by a chi-square test, had a difference in the average avrEMG between portions greater than 30%. 7 of the 11 subjects which showed these asymmetries had greater activation of the nondominant RA. This is in line with studies which point to asymmetries between sides of the RA in both muscle volume (Connell et al., 2006; Sanchis-Moysi et al., 2010) and increased demands for the nondominant RA in tennis strokes (Chow et al., 2003; Chow et al., 2009; Maquirriain et al., 2007). However, these results, like the other significant asymmetries found in this study, were found to be a protective factor for LBP, also contradicting the association between these differences and the potential for injury occurrence in tennis players (Ellenbecker & Roetert, 2004; Ng et al., 2002; Renkawitz et al., 2006; Renkawitz, Linhardt, & Grifka, 2008).

The MF slope of both the left ES-I and right EO was correlated with symptom intensity. However, the two correlations were in opposite directions. While a steeper (more negative) decline of the MF of the ES-I was associated with lower symptom intensity, a higher rate of MF decline of the right EO was corresponded by an increase in symptom intensity. Interpreted individually, this means that increased fatigability (as evaluated by the MF slope) of the left ES-I is a beneficial factor for symptom reduction. A possible explanation for this fact can, like the other changes in the extensor muscles' EMG parameters, be based on the load sharing theory. If subjects with LBP reach fatigue of the primary agonists more easily, it is more probable that they will maintain the testing position by recruiting other muscles, thus reducing symptom intensity. On the other hand, the association of a steeper MF slope and symptom increase found for the right EO could be explained by the aforementioned role of this muscle in the trunk rotation and stability. It is also worth noting that subjects who had LBP but were not prevented from training or playing had an increased MF slope of the left ES-I. In this way, the previously stated correlation of this muscle's fatigability and symptom intensity would make sense. As the symptoms' intensity increases, it is more likely that subjects will not be able to train or play because of them, so the MF slope results of these subjects are in accordance with the positive correlation found.

Endurance time and EMG data collectively show that healthy subjects had greater endurance of the flexor muscles and activation of dominant EO when compared with players who had LBP complaints over the last season. Activation of these muscles when they perform an antagonistic role is proposed to increase the dynamic stability of the spine, and this increase in activation during the correspondent test on healthy may reflect this phenomenon. These results support the concept of the importance of the abdominal muscles' activity in the prevention of LBP (Donatelli et al., 2012; McGill, Grenier, Kavcic, & Cholewicki, 2003; van Dieën, Kingma, & van der Bug, 2003). Altogether, results from this study indicate that abdominal wall endurance training should be a part of injury prevention schemes in tennis players, and these parameters play a more relevant role than those of the extensor muscles.

This study presents some limitations. Its retrospective nature may induce a recall bias; moreover, it has a relatively small sample size. Fatigue testing was performed in an analytical fashion, not taking into account functional demands of tennis strokes. Future studies should be of a prospective nature and measure fatigue as a result of tennis practice (eg. performing EMG analysis during endurance testing before and after a series of tennis strokes) while also adding other measurements like trunk range of motion and lumbar lordosis measurements. Co-contraction data should also be included in order to more accurately evaluate the impact of fatigue of the various muscle groups in the dynamic stability of the spine.

CONCLUSION

A trunk fatigue and activation profile in tennis players has been presented. Endurance time data indicates that healthy subjects show increased endurance of the abdominal wall muscles. EMG data supports the concept of load sharing of the extensor muscles in LBP subjects and increased activation of abdominal muscles in healthy subjects. This data encourages the inclusion of procedures to develop these parameters in LBP prevention protocols and the evaluation of their validity in terms of LBP prevention efficiency.

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Appendix 1 – Adapted Portuguese version of the Nordic Musculoskeletal Questionnaire (Mesquita et al., 2010)

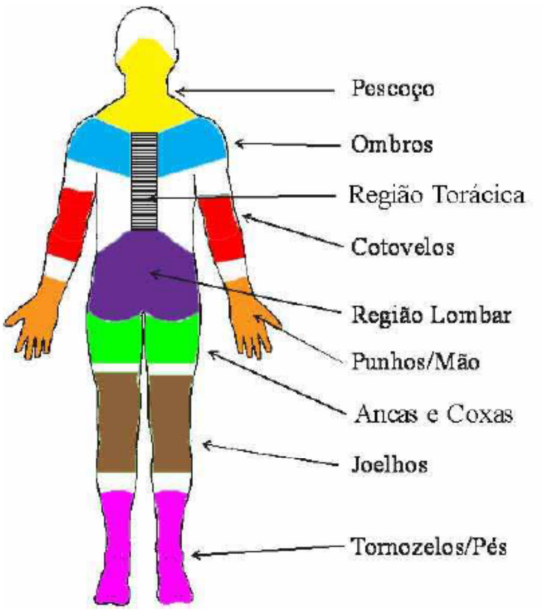
Instruções para o preenchimento

Por favor, responda a cada questão assinalando um "X" na caixa apropriada:

Marque apenas um "X" por cada questão.

Não deixe nenhuma questão em branco, mesmo se não tiver nenhum problema em qualquer parte do corpo.

Para responder, considere as regiões do corpo conforme ilustra a figura abaixo:



	Responda, apenas, se tiver algum problema		
Considerando os últimos 12 meses, teve algum problema (tal como dor, desconforto ou dormência) nas seguintes regiões:	Durante os últimos 12 meses teve que evitar treinar ou jogar por causa de problemas nas seguintes regiões:	Teve algum problema durante os últimos 7 dias, nas seguintes regiões:	Nos últimos 12 meses, consultou algum profissional de saúde (médico, fisioterapeuta) por causa desse problema?
Região lombar Não ☐ Sim ☐	Região lombar Não ☐ Sim ☐	Região lombar Não ☐ Sim ☐	Região lombar Não ☐ Sim ☐

Sem Dor	0	1	2	3	4	5	6	7	8	9	10	**Dor Máxima**

Appendix 2 – Adult consent form.

Declaração de consentimento informado

Designação do Estudo: Fadiga neuromuscular do tronco e dor lombar em tenistas

Eu, ____:

Tomei conhecimento de que o estudo se insere na disciplina de Dissertação do Mestrado em Ciências da Fisioterapia da Faculdade de Motricidade Humana e está sob a orientação do Prof. Doutor Pedro Pezarat-Correia e do Prof. Doutor Raul Oliveira.

Fui informado de que o Estudo de Investigação acima mencionado se destina a avaliar o tempo até à ocorrência de fadiga e a actividade muscular durante esse período em diversos grupos musculares do tronco.

Sei que neste estudo está prevista a realização de electromiografia de superfície e de quatro testes musculares tendo-me sido explicado em que consistem e quais os seus possíveis efeitos.

Foi-me garantido que todos os dados relativos à identificação dos Participantes neste estudo são confidenciais e que será mantido o anonimato.

Sei que posso recusar-me a participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto.

Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Aceito participar de livre vontade no estudo acima mencionado. Também autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

Nome do Investigador e contacto:

José Pedro Correia	Pedro Pezarat-Correia	Raul Oliveira
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jpcorreia.ft@gmail.com		

Data	Assinatura do participante
___/___/_____	____

Assinatura do investigador

____

Appendix 3 – Minor consent form.

Declaração de consentimento informado

Designação do Estudo: Fadiga neuromuscular do tronco e dor lombar em tenistas

Eu, ____, na qualidade de representante legal de ____:

Tomei conhecimento de que o estudo se insere na disciplina de Dissertação do Mestrado em Ciências da Fisioterapia da Faculdade de Motricidade Humana e está sob a orientação do Prof. Doutor Pedro Pezarat-Correia e do Prof. Doutor Raul Oliveira.

Fui informado de que o Estudo de Investigação acima mencionado se destina a avaliar o tempo até à ocorrência de fadiga e a actividade muscular durante esse período em diversos grupos musculares do tronco.

Sei que neste estudo está prevista a realização de electromiografia de superfície e de quatro testes musculares tendo-me sido explicado em que consistem e quais os seus possíveis efeitos.

Foi-me garantido que todos os dados relativos à identificação dos Participantes neste estudo são confidenciais e que será mantido o anonimato.

Sei que posso recusar-me a autorizar a participação ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto.

Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Autorizo de livre vontade a participação daquele que legalmente represento no estudo acima mencionado. Também autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

Nome do Investigador e contacto:	Orientadores e contacto:	
José Pedro Correia	Pedro Pezarat-Correia	Raul Oliveira
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jpcorreia.ft@gmail.com		

Data

___/___/_____

Assinatura do representante legal

____

Assinatura do participante

____

Assinatura do investigador

____

Appendix 4 – Information sheet given to participants.

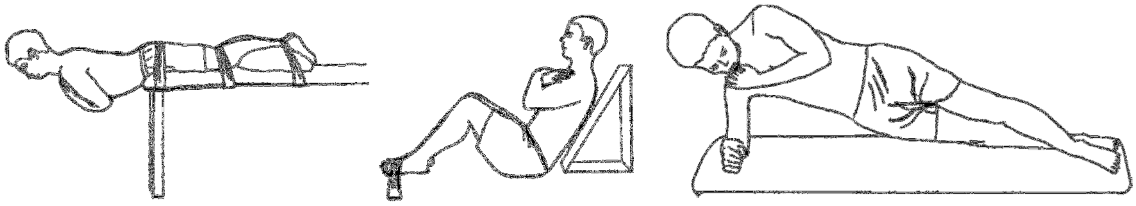
Documento de informação ao participante no estudo

Designação do Estudo: Fadiga neuromuscular do tronco e dor lombar em tenistas

Este documento tem como objectivo fornecer informação sobre o estudo acima mencionado, a ser realizado no âmbito da disciplina de Dissertação do Mestrado em Ciências da Fisioterapia da Faculdade de Motricidade Humana sob a orientação do Prof. Doutor Pedro Pezarat-Correia e do Prof. Doutor Raul Oliveira.

O estudo tem como objectivo esclarecer a relação entre a fadiga muscular do tronco e a dor lombar em tenistas. O protocolo de recolha de dados é composto pelos seguintes procedimentos:

- Medição do peso e altura do participante
- Recolha de informação relativa à prática de ténis e história de sintomas de dor lombar
- Medição do tempo até à fadiga e actividade eléctrica dos músculos do tronco nesse período em diversas posições:



A medição da actividade eléctrica dos músculos do tronco será realizada através de electromiografia de superfície. O processo envolve a colagem de eléctrodos sobre a pele e é totalmente indolor e não-invasivo. O protocolo de teste foi já extensivamente utilizado anteriormente e é considerado seguro para os participantes. A fadiga muscular local produzida durante o protocolo é temporária e de fácil recuperação.

A participação não trará nenhum benefício imediato aos participantes, mas poderá permitir uma melhor compreensão das causas da dor lombar em tenistas e de formas de a prevenir eficazmente, pelo que gostaríamos de contar com a sua colaboração neste estudo.

Agradecendo desde já a sua colaboração, encontro-me inteiramente disponível para prestar qualquer informação adicional.

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Appendix 5 – Additional tables

Table 14 - Endurance time (in seconds) tests between subjects with and without LBP on the last 7 days. Significant values denoted in bold.

Test	LBP-7d	Mean±SD	p
Flexor test	No	145,08±35,96	0,843
	Yes	140,25±60,53	
Extensor test	No	125,50±33,56	0,760
	Yes	130,25±33,60	
Left side bridge	No	79,58±27,25	0,433
	Yes	69,75±26,29	
Right side bridge	No	78,17±23,46	0,917
	Yes	77,00±25,13	

Table 15 - Endurance time ratios tests between subjects with and without LBP on the last 7 days. Significant values denoted in bold.

Ratio	LBP-7d	Mean±SD	p
Flexor/extensor	No	1,24±0,43	0,316
	Yes	1,06±0,29	
Right/left side bridge	No	1,05±0,28	0,408
	Yes	1,14±0,18	
Right side bridge/extensor	No	0,70±0,30	0,377
	Yes	0,60±0,14	
Left side bridge/extensor	No	0,67±0,37	0,473
	Yes	0,54±0,16	

Table 17 - Endurance time (in seconds) tests between subjects with LBP preventing them from training or playing on the last 12 months. Significant values denoted in bold.

Test	LBP-TR	Mean±SD	p
Flexor test	No	143,77±53,31	0,937
	Yes	142,00±31,24	
Extensor test	No	121,46±35,87	0,281
	Yes	138,43±24,64	
Left side bridge	No	77,77±29,79	0,640
	Yes	71,71±21,05	
Right side bridge	No	76,54±23,58	0,772
	Yes	79,86±25,04	

Table 17 - Endurance time ratio tests between subjects with LBP preventing them from training or playing on the last 12 months. Significant values denoted in bold.

Ratio	LBP-TR	Mean±SD	P
Flexor/extensor	No	1,23±0,42	0,354
	Yes	1,05±0,30	
Right/left side bridge	No	1,06±0,28	0,582
	Yes	1,12±0,55	
Right side bridge/extensor	No	0,71±0,29	0,242
	Yes	0,57±0,12	
Left side bridge/extensor	No	0,67±0,36	0,183
	Yes	0,52±0,13	

Table 18 - avrEMG and MFslope comparison between subjects with and without LBP on the last 7 days. Significant values denoted in bold.

	Muscle	N	LBP	Mean±SD	p
avrEMG	Left ES-I	12	No	1,78±0,27	0,192
		8	Yes	1,03±0,15	
	Left ES-L	12	No	1,07±0,16	0,409
		8	Yes	1,02±0,07	
	Right RA	12	No	1,67±0,46	0,481
		8	Yes	1,49±0,58	
	Right EO	12	No	1,47±0,48	0,354
		8	Yes	1,28±0,39	
	Right ES-I	12	No	1,19±0,21	0,079
		8	Yes	1,00±0,22	
	Right ES-L	12	No	1,08±0,15	0,137
		8	Yes	0,98±0,14	
	Left RA	12	No	1,64±0,48	0,625
		8	Yes	1,51±0,58	
	Left EO	12	No	1,70±0,41	0,140
		8	Yes	1,42±0,31	
MFslope	Left ES-I	12	No	-0,18±0,15	0,140
		8	Yes	-0,08±0,13	
	Left ES-L	12	No	-0,30±0,13	0,986
		8	Yes	-0,28±0,20	
	Right RA	12	No	-0,38±0,59	0,516
		8	Yes	-0,23±0,29	
	Right EO	12	No	-0,14±0,20	0,498
		8	Yes	-0,21±0,26	
	Right ES-I	12	No	-0,20±0,19	0,386
		8	Yes	-0,14±0,05	
	Right ES-L	12	No	-0,35±0,19	0,959
		8	Yes	-0,35±0,17	
	Left RA	12	No	-0,23±0,35	0,965
		8	Yes	-0,24±0,30	
	Left EO	12	No	-0,16±0,18	0,609
		7	Yes	-0,11±0,21	

Table 19 - avrEMG ratios comparison between subjects with and without LBP on the last 7 days. Significant values denoted in bold.

	Ratio	N	LBP	Mean±SD	p
avrEMG	L RA/ES-I	12	No	1,68±*0,73*	0,682
		6	Yes	1,54±*0,66*	
	L RA/ES-L	12	No	1,59±*0,78*	0,892
		6	Yes	1,66±*0,94*	
	R RA/ES-I	12	No	1,63±*0,56*	0,616
		6	Yes	1,72±*1,08*	
	R RA/ES-L	12	No	1,45±*0,46*	0,964
		6	Yes	1,74±*1,10*	
	R/L RA	12	No	1,02±*0,21*	0,682
		6	Yes	1,02±*0,11*	
	R/L EO	12	No	0,94±*0,38*	0,432
		8	Yes	1,08±*0,24*	
	R/L ES-L	12	No	1,03±*0,09*	0,201
		7	Yes	0,96±*0,10*	
	R/L ES-I	12	No	1,05±*0,19*	0,473
		7	Yes	0,99±*0,08*	
	Flexor/extensor	12	No	1,54±*0,55*	0,215
		6	Yes	1,73±*0,86*	
	Extensor right/left	12	No	1,04±*0,13*	0,153
		7	Yes	0,96±*0,08*	

Table 20 - Side-to-side avrEMG differences for each muscle pair for subjects with and without LBP on the last 7 days. Significant values denoted in bold.

LBP-7d	**Left-right ES-I**		**Left-right ES-L**		**Left-right RA**		**Left-Right EO**	
	Diff	**No Diff**	**Diff**	**No Diff**	**Diff**	**No Diff**	**Diff**	**No Diff**
No	1	11	0	12	3	9	5	7
Yes	0	8	0	7	0	6	2	5
Chi-square p	1,000		---		0,121		0,351	

Table 22 - avrEMG ratios comparison between subjects with and without LBP preventing them from training or playing over the last 12 months. Significant values denoted in bold.

	Ratio	N	LBP	Mean±SD	p
avrEMG	L RA/ES-I	11	No	1,61±0,75	0,791
		7	Yes	1,65±0,64	
	L RA/ES-L	11	No	1,48±0,76	0,596
		7	Yes	1,82±0,90	
	R RA/ES-I	11	No	1,59±0,56	0,860
		7	Yes	1,77±1,00	
	R RA/ES-L	11	No	1,41±0,46	0,860
		7	Yes	1,76±1,00	
	R/L RA	11	No	1,04±0,20	0,930
		7	Yes	1,00±0,14	
	R/L EO	12	No	1,06±0,33	0,167
		7	Yes	0,86±0,32	
	R/L ES-L	13	No	1,01±0,08	1,000
		7	Yes	0,98±0,13	
	R/L ES-I	13	No	1,03±0,13	0,699
		7	Yes	1,03±0,21	
	Flexor/extensor	11	No	1,57±0,60	0,708
		7	Yes	1,71±0,84	
	Extensor right/left	13	No	1,02±0,09	0,608
		7	Yes	1,00±0,16	

Table 1 - Side-to-side differences for each muscle pair for subjects with and without LBP preventing them from training or playing on the last 12 months. Significant values denoted in bold.

LBP	Left-right ES-I		Left-right ES-L		Left-right RA		Left-Right EO	
	Diff	No Diff	Diff	No Diff	Diff	No Diff	Diff	No Diff
No	0	13	0	13	3	8	4	8
Yes	1	6	0	7	0	7	3	4
Chi-square p	0,350		---		0,223		1,000	

Table 23 - Correlation values between EMG parameters and LBP status. Significant values denoted in bold.

	Muscle	Pearson's r	r^2	p
avrEMG	Left ES-I	-0,131	0,017	0,460
	Left ES-L	-0,033	0,001	0,852
	Right RA	-0,221	0,049	0,217
	Right EO	**-0,497**	**0,247**	**0,003**
	Right ES-I	-0,268	0,072	0,126
	Right ES-L	-0,062	0,004	0,726
	Left RA	-0,303	0,092	0,087
	Left EO	-0,230	0,053	0,198
MFslope	Left ES-I	0,133	0,018	0,454
	Left ES-L	-0,181	0,033	0,299
	Right RA	-0,195	0,038	0,262
	Right EO	-0,106	0,011	0,544
	Right ES-I	-0,126	0,016	0,472
	Right ES-L	-0,307	0,094	0,073
	Left RA	-0,173	0,030	0,321
	Left EO	-0,071	0,005	0,693

Table 24 - Correlations between EMG parameters and symptom intensity. Significant values denoted in bold.

	Muscle	Pearson's r	r^2	p
avrEMG	Left ES-I	-0,275	0,076	0,241
	Left ES-L	-0,297	0,088	0,204
	Right RA	-0,170	0,029	0,501
	Right EO	-0,366	0,134	0,112
	Right ES-I	-0,413	0,171	0,070
	Right ES-L	0,368	0,135	0,111
	Left RA	-0,084	0,007	0,741
	Left EO	0,018	0,000	0,941
MFslope	**Left ES-I**	**0,533**	**0,284**	**0,016**
	Left ES-L	-0,076	0,006	0,750
	Right RA	-0,136	0,018	0,567
	Right EO	**-0,522**	**0,272**	**0,018**
	Right ES-I	0,091	0,008	0,704
	Right ES-L	-0,175	0,031	0,460
	Left RA	0,088	0,008	0,714
	Left EO	-0,293	0,086	0,224

Table 2 - Correlations between avrEMG ratios, LPB status and symptom intensity. Significant values denoted in bold.

	Ratio	Pearson's r	r^2	p
LBP	L RA/ES-I	-0,280	0,078	0,121
	L RA/ES-L	-0,211	0,045	0,247
	R RA/ES-I	-0,160	0,026	0,383
	R RA/ES-L	-0,032	0,001	0,862
	R/L RA	-0,050	0,003	0,782
	R/L EO	**-0,382**	0,146	**0,031**
	R/L ES-L	-0,069	0,005	0,696
	R/L ES-I	-0,195	0,038	0,270
	Flexor/extensor	-0,155	0,024	0,396
	Extensor right/left	-0,128	0,016	0,470
Intensity	L RA/ES-I	0,184	0,034	0,464
	L RA/ES-L	0,332	0,110	0,178
	R RA/ES-I	0,275	0,076	0,270
	R RA/ES-L	0,552	0,305	0,152
	R/L RA	-0,073	0,005	0,773
	R/L EO	-0,128	0,016	0,602
	R/L ES-L	-0,303	0,092	0,194
	R/L ES-I	-0,109	0,012	0,648
	Flexor/extensor	0,312	0,097	0,207
	Extensor right/left	-0,230	0,053	0,328