LOCOMOTOR APPARATUS IN EXERCISE AND SPORTS

ORIGINAL ARTICLE

ELECTROMYOGRAPHIC ANALYSIS OF LOWER LIMB MUSCLES IN PROPRIOCEPTIVE EXERCISES PERFORMED WITH EYES OPEN AND CLOSED

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ABSTRACT

Introduction: Proprioception is a term used to describe all the neural information originated from the proprioceptors of the joints, muscles, tendons, ligaments and capsules, which is sent via afferent pathways to the central nervous system. EMG is the study of muscle function through the investigation of the electrical signal emanated from the muscle and it is also the study of the motor unit activity. Objective: To perform electromyographic analysis of the rectus femoris (RF) and tibialis anterior (TA) in different proprioceptive exercises (disc Freeman and rocker) with eyes open (EO) and eyes closed (EC). Methods: The analysis was conducted with 10 physically active male subjects, in a collection time of 10 seconds on each device with eyes both open and closed. Results: Thus, according to our findings, significant difference is observed when the proprioceptive exercises are performed with eyes open and closed, obtaining higher muscle activation, according to the electromyographic analysis, in the exercises with eyes closed, highlighting the importance of the visual system and how it interferes in the body's position when it is subjected to balance changes caused by the studied devices. Conclusion: Therefore, it can be concluded that the rectus femoris muscle did not show evident significant differences between the rocker and Freeman disc, as well as when the exercise was performed with eyes open or closed. The significant difference occurred was between the EO and EC Rocker and between Rocker EO and disk Freeman EC. Since the tibialis anterior muscle showed greater differences, especially with eyes closed, regardless of the device, which showed no significant differences between them.

Keywords: proprioception, electromyography, thigh and leg muscles.

INTRODUCTION

Proprioception is a term used to describe all the neural information originated in the proprioceptors of the articulations, muscles, tendons, capsules and ligaments, which are sent through afferent ways to the central nervous system, conscious or unconsciously, on the biomechanical relations of the articular tissues, which may influence on the muscular tonus, posture balance and articular stability[1].

Proprioceptive exercises are those which promote disturb in the sensory feedback system, which through the perturbation training promote dynamic reflex responses in order to generate neuromuscular control in a given articulation. Thus, these dynamic responses, that is to say, muscular contractions, produce metabolic, mechanical and myoelectric alterations in the skeletal muscular tissue, which can be monitored by surface electromyography which on its turn can provide important information about the muscles behavior when submitted to the different types of overload, in many angles and performance velocities[2].

Balance is defined in two ways: static and dynamic. Static and dynamic balance is kept by the vestibular (labyrinth, cochlear nerves, nuclei, ways and interrelations in the central nervous system), visual and proprioceptive systems, being the sensory receptors located in articulations, muscles and tendons. Disturb in one or more of these systems may cause alterations in balance. The vestibular system contributes to the maintenance of the body in balance and to the coordination of the head and the body movements. The vestibular signs alone are not able to provide information to the central nervous system, though[3].

The vestibular system participates in an accurate sensory data processing about the posture movements, playing many times potential roles in the posture control, since the visual system aids in the maintenance and orientation of an erect posture. Conscious and unconscious posture correction is possible through visual input. Although the visual system is important as a source of reference of verticality and for maintenance of natural body oscillation within the stability limits, it is not crucial to the posture control, since it is possible to maintain balance with eyes closed[3].

Electromyography (EMG) according to the neurophysiology category, joined to electroencephalography, records the brain functions and evoked potential which originate from muscles (from the electromyogram) or from muscles (through an electroneurogram). The electrical activity in muscles and nerves which control them is complex; thus, the EMG is a method for determination of electric characteristics of a particular muscle or muscular group or a particular nerve or a group of nerves[4].

The electromyographic exams have been used for over 40 years, and they provide an objective and accurate evaluation method. Since the procedure implies the insertion of needle electrodes in the muscle, many patients find the electromyographic exam unpleasant. It is usually soothing to the patient to understand that the kinesiological electromyography only records the electrical activity already present in the muscle in contraction, contrary to a possible introduction of electrical energy in his/her body[4].

The EMG is the study of the muscle function through the observation of the electrical signal which comes from the muscle, being also essentially the study of the activity of the motor unit[4, 5]. The surface electromyography which alone or combined may offer important information about the muscles behavior when submitted to the many different types of overload, many angles and performance velocity, as well as the evaluation of the myoelectrical behavior in many circumstances such as body and room temperature, neuromuscular training, to name some[6].

One of the most challenging aspects for the clinical professional is to understand the role of the proprioceptive neuromuscular control mediated after injury and its restoration through rehabilitation. The proprioception contributes to the accuracy in the motor programming necessary for the neuromuscular control of the movements and also for the muscular reflex, providing joined dynamic stability. The effect of ligament injury, resulting in mechanical instability and proprioceptive functional deficit contribute to instability, which could eventually lead to microtrauma and a new injury[2].

Deficit in proprioception has been demonstrated after the onset of injuries, in articular diseases and with age progression. Impulse originated from the muscles, fasciae, tendons and articular receptors may be affected by an injury, which may result in proprioceptive deficit. Thus, proprioceptive training and balance are recommended for restoration of the motor control of lower limbs. In clinical practice, the term 'balance' is frequently used with no clear definition, reminding that proprioception and balance are not synonyms: proprioception is a forerunner of balance and suitable function, while balance is the process through which we control the body's gravity center in relation to the base of support, either stationary or moving[2].

In order to use a variety of activities which improve balance, the physiotherapist should consider five general rules before initiating a treatment: the exercises should be safe and challenging, besides stress the many movement planes, should also incorporate a multisensory approach, initiate on stable surfaces with bilateral support and progress to unstable surfaces with unilateral support, progressing to functional exercises in sports. It is worth mentioning that none of the athletes should return to the games without having undergone a specific proprioceptive training period[7].

The theme of this study is concerned about a very relevant issue both in the clinical practice and sports environment, therefore it is believed that this study can provide data for the guidance of prevention and rehabilitation programs for articular or neuromuscular injuries.

Additionally, specifically in the sports environment, highlighting and making the competition teams aware of, including coaches, physical preparators, physiotherapists and the athletes themselves, the importance of having and g a good preparation of the motor apparatus both in order to avoid injuries and their reoccurrence as well as loss of athletes in important competitions.

Thus, the aim of this study was to perform an electromyographic analysis of the rectus femoris (RF) and tibialis anterior (TA) muscles in different proprioceptive exercises (Disc Freeman and Rocker) with eyes open and closed.

MATERIAL AND METHODS

Research characterization

The research about the electromyographic activity of the rectus femoris (RF) and tibialis anterior (TA) muscles in physically active individuals during different proprioception exercises is an experimental study and was developed in the Laboratory of Research in Kinesiological Electromyography (LAPEC), Biomedical Sciences Institute, Federal University of Uberlândia (UFU), in collaboration with the School Clinics of Physiotherapy of the University center of the Triangle (UNITRI), Uberlândia, MG.

Population and sample

The sample of this study was composed of 10 volunteers (male gender), physically active (obtained through a questionnaire) aged between 22 and 34 years. Only individuals who presented low body fat index and had no history of osteomuscular, neurodegenerative or infectious pathology were selected. All participants were clarified about the experiment procedure and signed the Free and Clarified Consent Form, according to the Guidelines on Research in Humans (resolution # 196/96 of the CNS). This study was approved by the Ethics and Research Committee (CEP) of the University Center of the Triangle (UNITRI) # 728200.

Electromyographer and software

The electromyographic record was obtained with the use of a computer electromyographer designed according to the international guidelines (MyosystemBr1 P84 / DataHominis Technology Ltda., Uberlândia, MG, Brazil), which had eight EMG acquisition channels originated from single or double differential electrodes and of differential pre-amplified for passive electrodes, four auxiliary channels which enables the acquisition of signals derived from devices such as load cells, electrogoniometers, force platforms and one reference channel, common to all electromyography channels.

The MyosystemBr1 P84 electromyographer also presents a display rate of 4 khz, gain adjustment programmed by software between 25 to 800 times (which allows total gain between 500 and 16000), galvanic isolation between the input circuits (in contact with the individual) and the power circuits (2.5 kv to infinite), entrance impedance of 1015 Ohms, 16 bits of resolution, high--pass filter of 15hz, low-pass filter programmed by software (250hz, 500hz, 1000hz or 2000hz) and integrated rechargeable battery for total portability.

The analog electromyographic signal acquired through the electromyographer, was converted to digital signal through an A/D converter (model PCI-DAS 1200, Myosystem, Prosecon Ltda, Uberlândia, MG, Brazil) which was attached to a laptop computer fed only by a battery; hence, the use of batteries by the two devices (electromyographer and laptop) guarantees almost completely the absence of interferences of 60Hz.

The electromyographic signals were collected and subsequently processed using a software application software Myosystem Br1 (version 2.22) for collection, visualization in real time and data processing and storage (DataHominis Tecnologia Ltda., Uberlândia, MG, Brazil).

Single-active differential surface electrodes (DataHominis Tecnologia Ltda., Uberlândia, MG, Brazil), composed of two pure silver parallel rectangular bars (10 mm long x 1 mm wide) and 10 mm apart were used for the acquisition of the electromyographic signals. These electrodes are attached to an acrylic resin capsule (2 cm wide x 0.6 cm high x 2.5 cm long) and connected to a 1.65 m long cable.

The signal was pre-amplified in the single differential electrode with gain of 20 times, entrance impedance of 10 GΩ and Common Mode Rejection Ratio (CMRR) of 92dB to 60Hz.

Concerning the site of placement of the electrodes on the surface of the rectus femoris and tibialis anterior muscles, the SENIAM parameters were used, that is to say, for the rectus femoris muscle the electrode was placed on the middle point (50%) of the line which goes from the antero-superior iliac spine to the upper side of the patella, while for the tibialis anterior, it was placed 1/3 on the line between the tip of the fibula and the tip of the medial malleolus (Figure1).

Another electrode was used as reference (Bio-logic Systems - SP Médica, Científica e Comercial Ltda., São Paulo, SP, Brazil), composed of a stainless steel disc (30mm of diameter x 1.5mm thick) attached to a 1 m long cable placed on the ulnar styloid process on the right antimere.

The electromyographic signals obtained during the proprioceptive exercises were submitted to a high-pass filter of 20Hz and low-pass of 500Hz, in order to eliminate possible mechanical interferences, since frequencies below 20Hz are stochastic and above 500Hz the motor units do not depolarize[8]. The frequency of the sampling used was of 2000Hz per channel during the entire collection.

Additional materials

- Shaving razor (BIC Sensitive Shaver, Bic Amazônia S.A., Manaus, AM, Brazil) for skin sanitation of the area for electrodes placement;
- Alcohol 70% and cotton for skin cleansing of the area for electrodes placement;
- Micropore hypoallergenic tape (Cremer, Cremer S.A. Têxtil, Blumenau, SC, Brazil) for attachment of the reference electrode and the surface electrodes cables on the region close to the muscles.

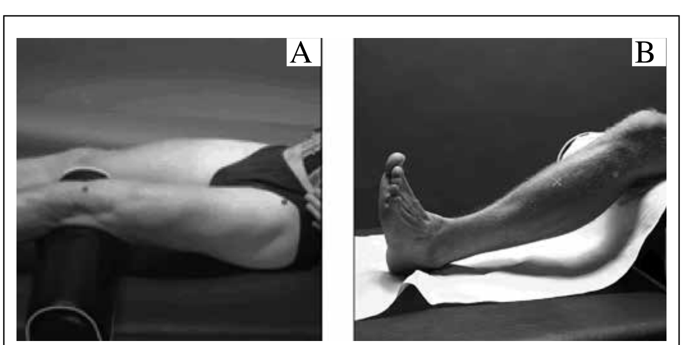

Figure 1. Example of the electrodes placement for uptake of the electromyograhic signal of the rectus femoris (a) and tibialis anterior (b) muscles according to SENIAM.

Data normalization

In order to establish suitable comparisons of the electromyographic activity of the same muscle and among different muscles during the performance of proprioceptive exercises, the raw values mean square (RMS) were normalized. The RMS normalized values were calculated from the raw mean values of RMS (mean of the RMS values obtained in three repetitions of the same movement). Moreover, the RMS values should be normalized in order to decrease the intrinsic variability of the inter and intraindividual electromyographic procedures during the tests, to allow more reliable electromyographic data[9].

In the proprioceptive exercises, the RMS raw values were normalized in percentage of the maximal voluntary isometric contraction (MVIC) for each muscle. After normalization of the electromyographic signals, the RMS raw values, expressed in mV, were substituted by RMSn values (RMS normalized values) expressed in percentage of MVIC (% MVIC).

Instruments

The devices used were the Rocker (ROC-figure 2) and the Disc Freeman (DIS-figure 3).

Figure 2. Rocker.

Figure 3. Disc Freeman.

Experimental protocol

In the beginning of each test, the electromyographic signals of each selected muscle were collected during three MVIC of five seconds, with the purpose to subsequently normalize the data. After the MVIC tests, the subjects performed the proprioceptive exercises.

The evaluation procedures of the muscular activity were performed on the dominant lower limb, with the individual barefoot, and for greater muscular activation, angulation of 30º of knee flexion was standardized using the universal goniometer. The knee position chosen provides greater articular instability, avoiding the terminal extension position, and consequently the stable articular position through the lock and bolt mechanism (position at which the ligaments are more relaxed, decreasing hence knee instability). The collection time of the electromyographic activity was of 10 seconds on each ground, using the rest time of one minute between collections, totalizing the mean of 4 ± 1 minute of collection and the performance order of the exercises in the proprioceptive devices was randomized (figure 4).

Statistical analysis

Data statistical analysis was performed with the computer program GraphPad Prism (version 3.0 – Graphpad Software, Inc) for calculation of mean, standard deviation, correlations and design of charts. Since the values presented normal distribution (gaussian), parametric tests were applied in all analyses.

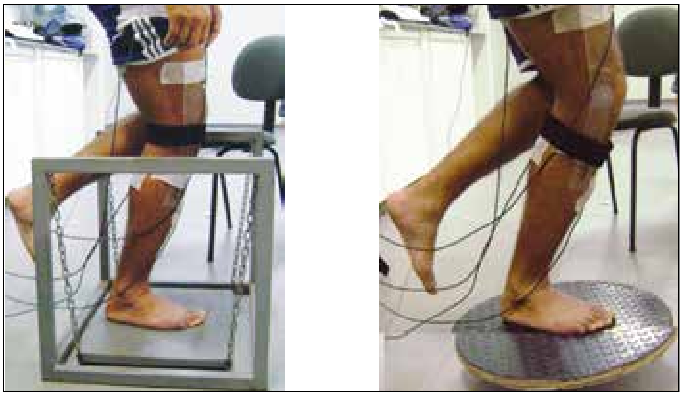

Figure 4. Example of a test on the rocker and on Disc Freeman, standardized with knee angle at 30°, with the aid of the goniometer.

Student's t test for paired samples was sued for comparison of the means of the RMSn values between different muscles in the same exercise or between the same muscle in different exercises with eyes open and closed.

RESULTS

The comparison of the mean values of RMSn obtained for the RF muscle between the different exercises evidences that:

1. There were significant differences ($p<0.05$) between the ROC-EO (7.8) and ROC-EC (13.2) exercises;
2. There were not significant differences ($p>0.05$) between the ROC-EO (7.8) and DIS-EO (9.3) exercises;
3. Significant differences occurred ($p<0.01$) between the ROC-EO (7.8) and DIS-EC exercises (15.8);
4. There were not significant differences ($p>0.05$) between the ROC-EC (13.2) and DIS-EO (9.3), ROC-EC (13.2) and DIS-EC (15.8), DIS-EO (9.3) and DIS-EC (15.8) exercises (figure 5).

Comparing the mean values of RMSn obtained for the TA muscle between the different exercises, it was observed that:

1. There were significant differences ($p<0.001$) during the ROC-EO (19.8) and ROC-EC (54.2) exercises;

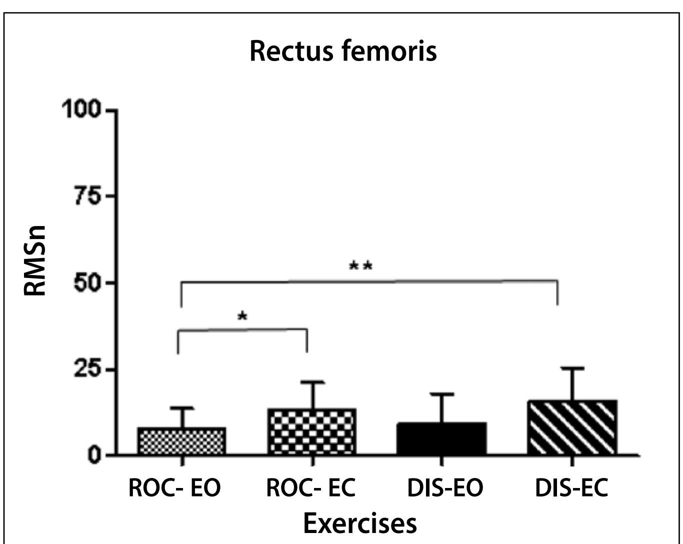

Figure 5. Comparison of the RMS (RMSn, expressed in % MVIC) normalized values of the RF muscle in 10 volunteers during the exercises Rocker with eyes open (ROC-EO) and eyes closed ROC-EC) and FREEMAN DISC with eyes open (DIS-EO) and eyes closed (DIS-EC). * $p<0.05$; ** $p<0.01$; *** $p<0.001$ as determined by the Student's t test.

2. There were not significant differences ($p>0.05$) during the ROC-EO (19.8) and DIS-EO (20.8) exercises;
3. Significant differences were observed ($p<0.001$) during the ROC-EO (19.8) and DIS-EC (51.0) exercises;
4. There were significant differences ($p<0.001$) between the ROC-EC (54.2) and DIS-EO (20.8) exercises;
5. There were no significant differences ($p>0.05$) between the ROC-EC (54.2) and DIS-EC (51.0);
6. There were significant differences ($p<0.001$) between the DIS-EO (20.8) and DIS-EC (51.0) exercises (figure 6).

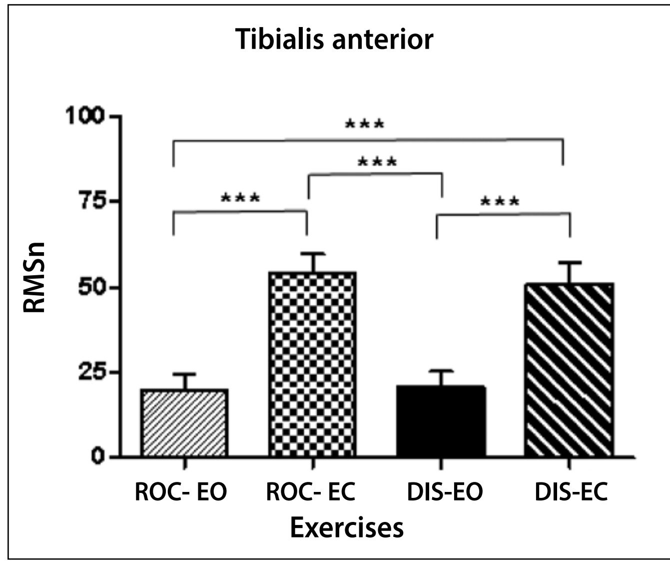

Figure 6. Comparison of the RMS (RMSn, expressed in % MVIC) normalized values of the TA muscle in 10 volunteers during the Rocker with eyes open (ROC-EO) and eyes closed (ROC-EC) and DISC FREEMAN with eyes open (DIS-EO) and eyes closed (DIS-EC) exercises. * $p<0.05$; ** $p<0.01$; *** $p<0.001$ as determined by the Student's t test.

DISCUSSION

Surface electromyography (EMG) allows the study in real time of the muscular function through the analysis of the electric signal generated during the muscle contraction, being possible from the electromyographic signal acquisition to interpret the motor apparatus under normal and pathological conditions. The literature is filled with papers about the electric signal generated by the muscle during a contraction. It is known that in the isometric contraction higher reproducibility of the myoelectric signal occurs compared to the isotonic contraction[10], a situation used in this investigation.

The proprioceptive exercises demonstrate a great prophylactic and rehabilitation action in musculoskeletal injuries, since they demand from the sensory modality a more competent way to obtain information concerning the movement sensation and articular position, based on elements from sources different from the visual, auditory or superficial skin[11].

When the central nervous system has the visual, vestibular and proprioceptive systems input available to perform the balance control, there is prevalence of visual signals over the other two, to inform about balance. It is for this reason that a person is able to reasonably maintain balance, even if the vestibular apparatus and the proprioceptive receptors are destroyed. At the eyes closed condition though, the body balance is under orientation only of two of the three input systems, which provide feedback to the central nervous system about the position and adjustment to be performed[11]. Thus, when the vision is suppressed, the action of the vestibular with the proprioceptive systems becomes more evident, leading to greater imbalance and difficulty in remaining in the same position for long, a situation observed during the data collection of the present research.

In a previous study, the tibialis anterior, tibialis posterior, fibularis longus and medial and gastrocnemius lateralis muscles were analyzed for being considered of key-activity during many situations of monopodal support, with eyes open and closed, both on stable and unstable surfaces. Thus, the collections were randomly distributed to the subjects in the research so that there was no chance for motor learning, including the unstable surfaces (trampoline and rocker) and the stable surface, both with eyes open and closed[3].

The results showed, in the analyses of the total means of the surfaces, greater muscular activation with eyes closed in comparison to the eyes open. Therefore, it was possible to observe the importance of the visual system in the body proprioception, emphasizing hence its action on the posture control and possible implications in the rehabilitation process. Additionally, the effect of the visual and proprioceptive information over the muscular activation of the ankle joint was observed in the maintenance of the static balance in healthy young subjects, especially in the rocker, which was also one of the devices used in our study, as well as the performance of the activity with eyes open and closed.

According to our findings, a significant difference was observed when the proprioceptive exercises are performed with eyes open and eyes closed, obtaining higher muscular activation according to the electromyographic analysis, in the exercises with eyes closed, stressing the importance of the visual system and how it interferes in the body position when it is submitted to balance variations caused by the devices studied (Rocker and disc Freeman), observing higher myoelectric activity of the tibialis anterior, corroborating the majority of the authors mentioned in this discussion. In agreement with the authors previously mentioned, 20 individuals from both genders were evaluated and collection time of 15 seconds of the electromyographic activity on each surface was used in their studies. In our study the target-public was of 10 individuals only from the male gender with the aim to obtain a more homogeneous sample, and the data collection time was of 10 seconds, since the volunteers could not remain longer time in each device due to the great difficulty in balancing generated, especially with eyes closed[2, 3].

Other authors performed research with eight women to investigate the electromyographic activity of the tibialis anterior and fibularis longus muscles during the posture maintenance on the proprioceptive platform on monopodal and bipodal support. The results obtained demonstrated that the tibialis anterior muscle presented higher activation in the exercises with balance platforms on bipodal support, in the antero-posterior and medium-lateral directions and on monopodal support in the antero-posterior direction, while the fibularis longus muscle presented higher activation only in the exercises on monopodal support in the medium-lateral direction. In another study, there was higher activation of the tibialis anterior and fibularis longus muscles in comparison to the other muscles (gastrocnemius medialis and lateralis and tibialis posterior), it shows that both muscles are important dynamics stabilizers in the ankle articulation; the tibialis anterior muscle acting as an invertor and dorsiflexor and the fibularis longus muscle acting as an evertor and plantar flexor. The inversion and eversion function must be highlighted, since the majority of the unstable surfaces presented great lateral-medial instability. It may explain the reason why these two muscles were more active during all the perturbation exercises[2, 12].

In another electromyographic study, the tibialis anterior and gastrocnemius medialis of five individuals were evaluated during the use of two models of balance platforms on different support. The results obtained evidenced higher myoelectric activity in the gastrocnemius medialis muscle comparing with the tibialis anterior during the tests with feet closer and with feet more apart, on both proprioceptive platforms[13]. Differently from the findings of the study mentioned before, the tibialis anterior muscle presented higher electromyographic activity on all surfaces, both stable and unstable, being the muscle more demanded.

Therefore, in a general analysis, it was observed that the rectus femoris muscle is not as important in the balance function as the ankle muscles and consequently its function is more specific for the stabilization of the knee and patella articulations in a dynamic manner.

Thus muscle has been issue of studies through electromyography in many investigations with the aim to verify its participation in movements of the hip and knee articulations, both in the sports and clinical fields[14]; however, there are some gaps in the literature about the electric activity of the thigh muscles in proprioceptive exercises.

Thus, it is important that studies which analyze the electromyographic activity of thigh muscles during proprioceptive exercises are carried out, becoming an useful tool for designing of rehabilitation protocols of ligament, capsular, articular and muscular injuries in order to establish the dynamic balance of the knee articulation.

It should be highlighted that in the present investigation a proprioceptive training time was not used, a fact which may change the muscular recruiting factor. Thus, future studies which perform an electromyographic comparison before and after a training period are suggested.

Therefore, the results in the literature and the findings of this study indicate that the exercises performed on the Rocker and the Disc Freeman, significantly increased the electromyographic activity and can be used in the prevention and rehabilitation of injuries, especially on the ankle. Furthermore, it was possible to observe the importance of the visual system in the body's proprioceptive action, demonstrating that its absence may be an example of evolution of proprioceptive exercises and activities according to the patient's capacity in developing the task with expected balance for a specific or non-specific activity.

It can be concluded according to the methodology applied in this study that the rectus femoris muscle presented similar electromyographic activity in the different exercises, and significant differences only occurred in between the ROC-EO x ROC-EC and ROC-EO x DIS-EC, in which higher electric activity was observed in the exercises with eyes closed. Regarding the tibialis anterior muscle, more remarkable significant differences were verified, especially when the exercises with eyes open and closed are compared; however, when the devices in the same situation are compared (ROC-EO x DIS-EO and ROC-EC x DIS-EC) no significant differences are observed, demonstrating that the devices provide similar electric activity in the referred muscle. Thus, the great participation of the tibialis anterior muscle becomes evident in proprioceptive exercises and activities according to the results of the electromyographic analysis, showing that this muscle plays an important role in the possibility to improve balance being activated while dynamic stabilizer, increasing the possibilities to avoid the onset of ligament, muscular and articular injuries as well as their recurrence. It was also demonstrated in the study that the rectus femoris muscle has higher function on the knee level, being little activated electromyographically, even without the visual stimuli, in the proprioceptive exercises and activities, being its patellar and the vastus muscles stabilization function more significant, besides being a more dynamic and important muscle for activities such as kicking.

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REFERENCES

1. Antes DL, Katzer JI, Corazza ST. Coordenação motora fina e propriocepção de idosas praticantes de hidroginástica. RBCEH 2008;5:24-32.
2. Ferreira LAB, Rossi LAB, Pereira WM, Vieira FF, Paula Jr AR. Análise da atividade eletromiográfica dos músculos do tornozelo em solo estável e instável. Fisioter Mov 2009;22:177-87.
3. Ferreira LAB, Pereira WM, Oliveira DC, Figueiredo RR, Albuquerque CE, Vieira LS, et al. Congresso Brasileiro de Engenharia Biomédica, 21, 2008, São José dos Campos. Comparação eletromiográfica dos estabilizadores dinâmicos do tornozelo com os olhos abertos e fechados, p. 1715-8.
4. Portney L. Eletromiografia e testes de velocidade de condução nervosa. In: Sullivan O, Susan B, Shmitz-Thoma J. Reabilitação física: avaliação e tratamento. 2. ed. São Paulo: Manole, 1993, p.183-223.
5. Basmajian JV, De Luca CJ. Muscles alive: their functions revealed by electromyography. 5. ed. Baltimore, MD: Williams and Wilkins, 1985.
6. Ferreira LAB, Pereira WM, Vieira FF, Rossi LP. XI Encontro Latino Americano de Iniciação Científica e VII Encontro Latino Americano de Pós-Graduação, 2007, Guarapuava. Ativação eletromiográfica dos músculos da perna em exercícios proprioceptivos na reabilitação de tornozelo: uma revisão bibliográfica, p. 1119-22.
7. Beirão ME, Marques TAR. Estudo dos fatores desencadeantes da entorse do tornozelo em jogadores de futebol e elaboração de um programa de fisioterapia preventiva. Revista de pesquisa e extensão em saúde 2007;3:1-7.
8. Konrad P. The ABC of EMG: a pratical introduction to kinesiological eletromyography. Noraxon Inc. USA, p. 27, 2005. [acesso 2008 nov 26]. Disponível em: www.noraxon.com.
9. Silva DCO. Avaliação eletromiográfica dos músculos peitoral maior, bíceps braquial, pronador redondo e flexor ulnar do carpo envolvidos no esporte luta de braço. 2004. 129 f. Dissertação (Mestrado em Anatomia Funcional) - Instituto de Ciências Biomédicas, Universidade de São Paulo, São Paulo, 2004.
10. Amorim L. Estudo eletromiográfico de força de preensão em indivíduos sadios. Dissertação de Mestrado apresentada ao Programa de Pós-graduação Engenharia Biomédica. Instituto de Pesquisa e Desenvolvimento da Universidade do Vale do Paraíba. 2003; 60 p.
11. Baldaço FO, Cadó VP, Souza J, Mota CB, Lemos JC. Análise do treinamento proprioceptivo no equilíbrio de atletas de futsal feminino. Fisioter Mov 2010;23:183-92.
12. Cunha PL, Bonfim TR. Ativação eletromiográfica de exercícios sobre a prancha de equilíbrio. Revista Fisioterapia Brasil 2007;8:192-7.
13. Oliveira FB, Paula RH, Oliveira CG, Dantas EHM. Avaliação de dois modelos de tábuas proprioceptivas com dois tipos de apoios por meio da eletromiografia de superfície. Revista Fisioterapia Brasil 2006;7:187-90.
14. Moraes AC, Bankoff ADP, Okano AH, Simões EC, Rodrigues CEB. Análise eletromiográfica do músculo reto femoral durante a execução de movimentos do joelho na mesa extensora. R Bras Ci e Mov 2003;11:19-23.