LOCOMOTOR APPARATUS IN EXERCISE AND SPORTS

Influence of Unilateral Fatigue of Lower Limbs on the Bilateral Vertical Jump

Original Article

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ABSTRACT

It is common to observe bilateral strength deficit during the vertical jump. This is characterized by lower strength produced during bilateral contractions, when compared to the sum of the unilateral contractions of similar muscles. There is not much scientific knowledge about the effect of unilateral fatigue on bilateral activities. The aim of this study was to investigate the effect of unilateral fatigue on bilateral deficit performance during bipedal vertical jump. Ten sedentary young adults unilaterally fatigued each lower limb and performed vertical jumps (bipedal and unipedal). We measured the vertical ground reaction force and myoelectrical activity to each lower limb and conditions (pre-fatigue, fatigue of the dominant limb (DF) and non dominant limb (NDF) were measured. Differences between tasks and conditions only on the pre-fatigue ($p=0.030$) were observed. Differences were observed for the bipedal vertical jump between pre-fatigue and DF ($p=0.005$), and unipedal vertical jump between pre-fatigue and DF ($p<0.001$) and NDF ($p<0.001$). We only observed change on the performance of bipedal vertical jump during the DF condition. We observed a trend to the asymmetry index decrease for the muscular action of the fatigued contralateral lower limb by electromyography. The results suggest that there is a common command where the nervous system considers the muscles simultaneously activated as a unit, except in conditions of unilateral lower limb fatigue.

Keywords: fatigue, countermovement jump, bilateral strength deficit.

INTRODUCTION

Bilateral strength deficit is a commonly verified phenomenon when the voluntary maximal strength levels produced during bilateral contractions are lower than during unilateral contractions of the same muscles, when they are added[1-4], being is description firstly published in 1961 by Henry and Smith[5]. Deficit in bilateral strength has been observed in lower limbs[6-9] and upper limbs[7,10]; however, its magnitude is usually lower in upper limbs (2%-20%) compared to lower limbs (13%-25%)[7].

The mechanisms responsible for the bilateral deficit are currently little known, partly for being a non-visible phenomenon in all experimental conditions[7]. However, there are many theories related to deficit of bilateral strength such as: spinal inhibitory reflex[11], reduction of motoneurons excitability[1], inter-hemispheric inhibition[1,12], influence of postural instability[7,13], influence of the strength-velocity curve of the active muscles[3,6,14], differences in the neuromuscular control between unilateral and bilateral contractions[3].

Several studies have reported that during bilateral jumps, the individuals reach lower height in maximal vertical jump compared to the maximal height reached in unilateral jumps, when the leg is bent[6,15-17]. The implication that the amount of work produced by one leg in a bilateral jump is lower than in unilateral jumps is confirmed by inverse dynamics analysis[15].

During the sustained muscular contraction or the performance of repetitions, the muscle may face exhaustion and fail to maintain the desired strength, power or work[18,19]. Therefore, muscular fatigue is considered progressive loss in the generation of muscular strength, or decline in the development of strength through progression of the number of repetitions[18] and can also affect many other factors related to human performance: movement coordination, accuracy, reaction time and proprioceptive capacities[19-21].

Several studies report the effect of unilateral or bilateral fatigue in tasks of same characteristic (e.g. unilateral fatigue with unilateral jump); however, little is known about the effect of unilateral fatigue on bilateral activities. Thus, the aim of this study was to verify the effect of unilateral fatigue, dominant and non-dominant sides over performance and bilateral deficit during the bilateral vertical jump.

MATERIALS AND METHODS

Subjects

The sample was composed of 10 sedentary, healthy, male young adults (age: 25 ± 4 years; height: 176 ± 8cm, weight: 73 ± 12kg), thigh and lg circumferences were not different between right and left sides (table 1). The subjects were selected and included after having been confirmed they did not present injuries which could compromise performance, or even peripheral and /or central neurological disorders. The subjects were informed about the experimental procedures and signed the Free and Clarified Consent Form, approved by the Ethics in Research Committee of the Physical Education and Sports College of the University of São Paulo.

Procedures

Initially, the dominant lower limb was determined through the kick a ball test[22]. Prior to the jump tasks, the subjects performed unilateral one-repetition maximum test (1RM) in the leg press exercise (Cybex, Int, USA). Subsequently to the procedures

Table1. Thigh and leg perimetry (Dominant and non-dominant).

Segment	Mean ± SD
Dominant Thigh	54.7 ± 4.5
Non-dominant Thigh	54.6 ± 4.5
Dominant Leg	36.5 ± 2.5
Non-dominant Leg	36.5 ± 2.6

mentioned above, they performed bilateral and unilateral jump with maximal contra movement (CMJ) (dominant limb (Dom) and non-dominant limb (Ndom). The forces to ground reaction were measured by a strength platform (OR6, AMTI Inc., USA), and the myoelectric activity (EMG) of the vastuslateralis muscle (in each limb) was measured through an electromyographer (Noraxon USA, Scottsdale, AZ). The body hair was removed from the region of the electrodes placement, and light skin abrasion was performed for dead cells removal and reduction of impedance for the EMG. Pairs of Ag/AgCl round self-adhesive passive surface electrodes, with 1-cm diameter and 2-cm spacing from center to center between electrodes, associated to a conducting gel were used. The electrodes were placed on the skin surface on the vastus lateralis muscle, specifically at 2/3 between the antero superior iliac spine and lateral of the patellar lateral line following the muscle fibers orientation and placed in the muscle venter (SENIAN, 2010). The 1-cm Ag/AgCl self-adhesive reference electrode associated to a conduction gel, was placed on the clavicle bone prominence. The data acquisition was done at 1,080Hz frequency and data were processed through a written routine on the Matlab software (Mathworks Inc., USA).

The bilateral vertical jump with contra movement (CMJ) was performed with subjects standing still on a strength platform, with feet apart at hip width and upper limbs front crossed at chest level. Unilateral CMJ followed the same orientation; however, only one leg remained in contact with the strength platform (dominant or non-dominant). The subjects were told to perform here maximal jumps and keep their knees extended during the flying phase; the two best jumps out of these three were analyzed. Each jump had a five-second interval in between and the trials were randomized between tasks.

The CMJ tasks (bilateral and unilateral) were initially performed at lack of fatigue condition (pre-fatigue) and at the following neuromuscular fatigue conditions: dominant limb fatigue (DF), non-dominant limb fatigue (NDF).

Fatigue protocol

The fatiguing task was to perform hip, knee and ankle extension movements in the leg press machine (Cybex Int., USA). The unilateral fatigue protocol consisted of two bouts with 40% of 1RM intensity until exhaustion characterized by failing in the movement in the concentric muscular action. Interval between these bouts was of 20 seconds and cadence self-selected, resulting in approximately 50 repetitions in each bout. The unilateral fatigue conditions were randomized between subjects. Following the fatigue protocol, the subject performed the determined jumps (bilateral and/or unilateral, randomly performed). A 10-minute recovery pause was given after the jumps with subsequent beginning of the fatigue protocol on the contrary lower limb, besides the jumps performance.

Data analysis

The platform data were filtered with a Butterworth fourth order low-pass filter and zero delay with of 100Hz cohort frequency for the CMJ data. The maximum height of vertical dislocation through the velocity peak (defined by the double integration of the vertical reaction force of the ground) in the propulsive phase of the CMJ was calculated for the bilateral and unilateral CMJ. The following formula was used:

$$v_{takeoff}^{2} / (2g)$$

Where g is the gravity force (g = 9.8m/s^2)[23].

Specifically to the unilateral CMJ, the sum of the maximal heights of each limb was calculated during all conditions: pre-fatigue, dominant fatigue (fatigued dominant limb + non-fatigued non-dominant limb) and non-dominant fatigue (fatigued non-dominant limb + non-fatigued dominant limb).

Processing of the EMG signal followed this order: the EMG signals were filtered with a fourth order passband filter between 20-400Hz, and delay of zero phase, the root-mean square with a movable window of 50ms was used, being normalized by the activation peak during the propulsive phase of the jumps. The EMG data were defined by the beginning and end of the CMJ propulsive phase and the integral of the myoelectrical activation defined by the activation time (IEMG) of the vastuslateralis muscle of each limb. An asymmetry index (AI) between the dominant limb (Vd) and the non-dominant limb ((Vnd) was hence calculated as follows:

$$AI = 100 * \frac{(V_d - V_{nd})}{(V_d + V_{nd})/2}$$

STATISTICAL ANALYSIS

The descriptive analysis involved measurements of central tendency and variability. All data were reported through the mean and standard deviation (SD) of the mean. Normality and homogeneity of the variances were verified using the Kolmogorov-Smirnov *and* Levene test, respectively. Paired Student's *t* test was used to verify the differences (bilateral deficit) between the maximal heights of the jumps between the unilateral tasks and the myoelectric activity of the vastus lateralis muscle at the fatigue conditions. 2x3 ANOVA was used for the maximal height of the bilateral jumps, having as factor the task (bilateral and unilateral) and the fatigue condition (lack of fatigue, fatigue of the dominant limb and fatigue of the non-dominant limb), being the last measurements repeated. Sidak *post hoc* was used. Significance level (α) of 0.05 was used for all statistical tests, through the SPSS software, version 15.0.

RESULTS

Initially, unilateral jumps were used to certify that the unilateral fatigue was really induced (height of the unilateral jumps after unilateral fatigue was significantly lower for the two legs; dominant leg: $t(9) = 7.13$, $p < 0.001$; non-dominant leg: $t(9) = 7.65$, $p < 0.001$)

(figure 1). The decrease in the unilateral jumps after fatigue induction was of 28.9% and 31%, dominant and non-dominant leg, respectively.

Figure 2 shows the mean andstandard deviation values of the height of the jump with bilateral and unilateral contra movement, at the lack of fatigue and unilateral fatigue conditions (dominant and non-dominant). Statistical analysis (ANOVA) showed interaction between tasks and fatigue conditions ($F(2.18) = 11.34$, $p = 0.001$); the *post hoc* presented differences only between the tasks at the lack of fatigue condition ($p = 0.030$). The main effect between the fatigue conditions ($F(2.18) = 27.42$, $p < 0.001$) was also presented; the *post hoc* presented significant differences for the bilateral task at the pre-fatigue and fatigue of dominant limb conditions ($p = 0.005$) and for the unilateral task at the pre-fatigue and fatigue of dominant limb ($p < 0.001$) and non-dominant limb ($p < 0.001$).

Figure 3 presents the mean and SD values for the asymmetry index by the difference between the dominant limb and non-dominant limb in EMG of the vastus lateralis muscle. This index was calculated for the pre-fatigue and post-fatigue conditions (dominant and non-dominant limbs). It represents the tendency of participation ofone limb over the contralateral, meaning that the positive values show higher participation of the dominant limb compared to the non-dominant limb, while negative values show higher participation of the non-dominant limb compared to the dominant one. There were not significant diferences for the asymmetry indices for the fatigue conditions.

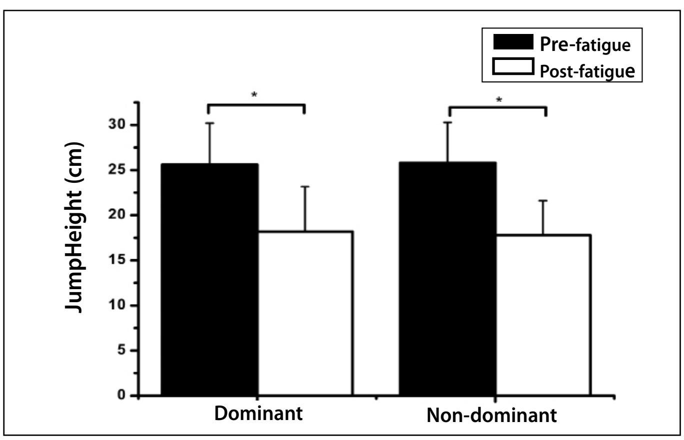

Figure 1. Mean ± SD of the maximal height of the jumps with contra-movement for the unilateral task, at the lack of fatigue and unilateral fatigue conditions.*p<0.05.

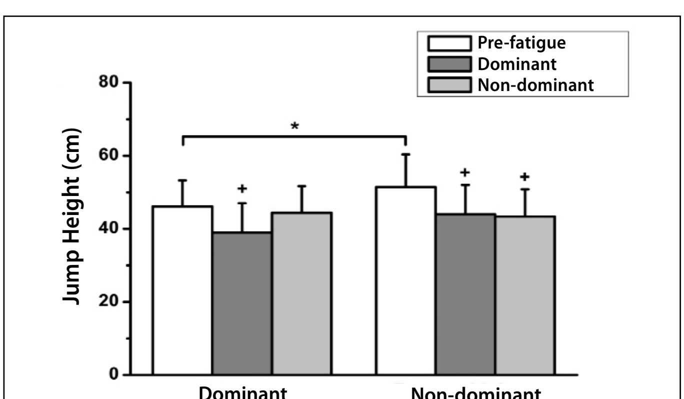

Figure 2. Mean ± SDof the maximal height of the jumps with contra-movement for the bilateral and unilateral tasks [Dominant + Non-dominant (Dom+Ndom)], at lack of fatigue and unilateral fatigue conditions (dominant and non-dominant).* difference between tasks, p<0.05; + difference concerning the pre-fatigue condition, p<0.05.

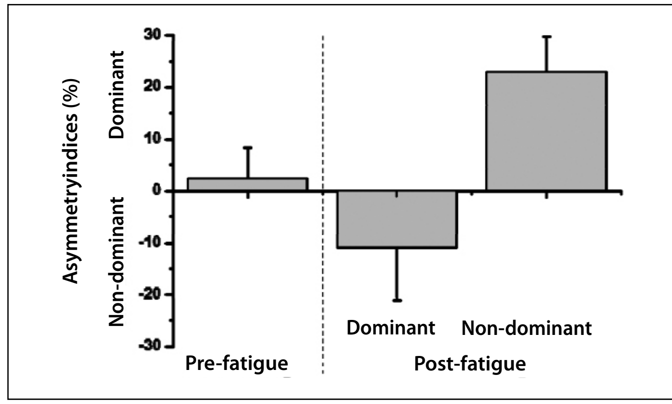

Figure 3. Mean ± SDof the asymmetry indices for the integrated electromyography of the vastus lateralis muscle during the propulsive phase of the jumps with contra-movement for the bilateral tasks at the unilateral pre-fatigue and post-fatigue conditions (dominant and non-dominant).

DISCUSSION

The aim of the present study was to verify the unilateral fatigue effect, dominant and non-dominant sides, over performance and bilateral deficit during the bilateral vertical jump. Initially, similar decrease was observed in performance of the unilateral maximal jumps in both limbs (dominant and non-dominant), which does not corroborate other studies which point higher susceptibility to fatigue of the non-dominant limb compared to the dominant one[24-26]. However, the studies mentioned analyzed muscles of upper limbs, which presented differences in their muscle fibers composition between the right and left limbs, afactor which could have influenced on the level of fatigue reached. It is known that muscles with higher percentages of fast contraction fibers (type II) are more prone to fatigue[27]. In the case of lower limbs, there is evidence that there is higher percentage of type II fibers in the vastus lateralis muscle[27]; hence, lower resistance to fatigue is expected. However, evidence on the differences in the composition of muscle fibers between limbs, as well as which factor could directly affect performance of jumps is scarce[21].

Considering that the level of fatigue reached by both limbs is similar, and supposing that such fatiguing condition equally affects performance during bilateral tasks, it was curiously verified that only during the fatigue condition of the dominant limb there was alteration in performance of bilateral jumps.Therefore, it seems that the dominant limb has greater influence than the non-dominant one at maximal height of the bilateral jumps. Such results above also corroborate the electromyographic findings of the present study, which present tendency to decrease in the participation of the vastus lateralis muscle during the propulsive phase of the bilateral jumps when the ipsilateral limb is fatigued[26].

Electromyography is the result of central commands to the muscles, and can provide information of the neural mechanisms related to the bilateral deficit[3]. The amplitude of the myoelectric signal depends on the membrane properties of the muscle fibers and the timing of the action potential of the motor units, reflecting central and peripheral properties of the neuromuscular system, both at normal and fatigue conditions[3,28]. At the lack of fatigue condition, both limbs reached similar muscular activation values; however, when fatigue is present in one of the limbs, higher activation of the contralateral limb can be verified. In the specific case of the bilateral jump with fatigue in the dominant limb, increase of the electromyographic activation was not suficiente to maximize the jump and produce maximal Heights similar to the lack of fatigue condition, a fact occurred only when the non-dominant limb was fatigued.

Many studies show that maximal bilateral voluntary contractions reach lower values than the sum of the unilateral strength, a phenomenon named bilateral strength deficit[21]. During the study, the presence of bilateral deficit only at the lack of neuromuscular fatigue condition was observed, which does not corroborate the findings by Yoshioka *et al*.[29]. Unilateral fatigue (dominant or non-dominant limb) seems to have influenced on the differences between height of the bilateral jumps and the sum of unilateral jumps (Dom+Ndom).

It can be speculated that there is a common command[24] which may indicate that the muscles simultaneously activated, in order to generate maximal strength, are seen by the nervous system as an unit and control them in a similar way[1]. However, it seems that fatigue of only one of the limbs alters this common command and dissociating the command for both limbs[1].

In practical terms, training, as well as the familiarization to tasks, may reduce the bilateral strength deficit minimizing the asymmetry, especially at fatiguing conditions, in which the control dissociation may modify the overload between limbs, since tasks which present asymmetry between limbs are more prone to injuries during physical performance[30-36].

CONCLUSION

Previous unilateral exercise with dominant lower limb until exhaustion resulted in subsequent decrease in bilateral vertical jump performance.This is interesting information for physical preparators and coaches, which may guide their athletes from training prescription to sports conduct. Associated to this performance response, there was a tendency to decrease in participation of the vastus lateralis muscle during the propulsive phase of the bilateral jumps when submitted to ipsilateral fatigue, especially for the dominant side.

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REFERENCES

1. Oda S. Motor control for bilateral muscular contractions in humans. Jpn J Physiol 1997;47:487-98.
2. Owings TM, Grabiner MD. Fatigue effects on the bilateral deficit are speed dependent. Med Sci Sports Exerc 1998;30:1257-62.
3. Rejc E, Lazzer S, Antonutto G, Isola M, Di Prampero PE. Bilateral deficit and EMG activity during explosive lower limb contractions against different overloads. Eur J Appl Physiol 2010;108:157-65.
4. Kuruganti U, Murphy T, Pardy T. Bilateral deficit phenomenon and the role of antagonist muscle activity during maximal isometric knee extensions in young, athletic men. Eur J Appl Physiol 2011;111:1533-9.
5. Henry FM, Smith LE. Simultaneous vs. separate bilateral muscular contractions in relation to neural overflow theory and neuromotor specificity. Res Q Exerc Sport 1961;32:42-7.
6. Bobbert MF, Graaf WW, Jonk JN, Richard Casius LJ. Explanation of the bilateral deficit in human vertical squat jumping. J Appl Physiol 2005;100:493-9.
7. Magnus CRA, Farthing JP. Greater bilateral deficit in leg press than in handgrip exercise might be linked to differences in postural stability requirements. Appl Physiol Nutr Metab 2008;33:1132-9.
8. Cresswell AG, Ovendal AH. Muscle activation and torque development during maximal unilateral and bilateral isokinetic knee extensions. J. Sports Med Phys Fitness 2002;42:19-25.
9. Jacobi JM, Chilibeck PD. Bilateral and unilateral contractions: possible differences in maximal voluntary force. Can J Appl Physiol 2001;26:12-33.
10. McLean SP, Vint PF, Stember AJ. Submaximal expression of the bilateral deficit. Res Q Exerc Sport 2006;77:340-50.
11. Ohtsuki T. Decrease in human voluntary isometric arm strength induced by simultaneous bilateral exertion. Behav Brain Res. 1983;7:165-78.
12. Post M, Van Duinen H, Steens A, Renken R, Kuipers B, Maurits N, Zijdewind I. Reduced cortical activity during maximal bilateral contractions of the index finger. Neuroimage 2007;35:16-27.
13. Herbert RD, Gandevia SC. Muscle activation in unilateral and bilateral efforts assessed by motor nerve and cortical stimulation. J Appl Physiol 1996;70:306-16.
14. Yamauchi J, Mishima C, Nakayama S, Ishii N. Force-velocity, force-power relationships of bilateral and unilateral leg multi-joint movements in young and elderly women. J Biomech 2009;42:2151-7.
15. Van Soest AJ, Roebroeck ME, Bobbert MF, Huijing PA, Van Ingen Schenau GJ. A comparison of the one-legged and two-legged countermovement jumps. Med Sci Sports Exerc 1985;17:635-9.
16. Vint PF, Hinrichs RN. Differences between one-foot and two-foot vertical jump performances. J Appl Biomech 1996;1996:12.
17. Challis JH. An investigation of the influence of bi-lateral deficit on human jumping. Hum Mov Sci 1998;17:307-25.
18. Vedsted P, Larsen AH, Madsen K, Sjogaard G. Muscle performance following indeced by isotonic and quasi-isometric contractions of rat extensor digitorum longus and soleus muscles in vitro. Acta Physiol Scand 2003;178:175-86.
19. Ament W, Verkerke GJ. Exercise and Fatigue. Sports Med 2009;39:389-422.
20. Magdigan ML, Pidcoe PE. Changes in landing biomechanics during a fatiguing landing activity. J Electromyogr Kinesiol 2003;13:491-8.
21. Gandevia SC. Spinal and supraspinal factors in human muscle fatigue. Physiological Rev 2001;81:1725-76.
22. Maulder P, Cronin J. Horizontal and vertical jump assessment: reliability, symmetry, discriminative and predictive ability. Phys Ther Sport 2005;6:74-82.
23. Dowling JJ, Vamos L. Identification of kinetic and temporal factors related to vertical jump performance. J Appl Biomech 1993;9:95-110.
24. De Luca CJ, Sabbahi MA, Roy SH. Median frequency of the myoelectric signal. Eur J Appl Physiol 1986;55:129-42.
25. Tanaka M, McDonald MJN, Davies CTM. A comparison of the mechanical proprieties of the first dorsal interosseous in the dominant and non-dominant hand. Eur J Appl Physiol 1984;53:17-20.
26. Oda S, Moritani T. Cross-correlation of bilateral differences in fatigue during sustained maximal voluntary contraction. Eur J Appl Physiol 1995;70:305-10.
27. Hamada T, Sale DG, MacDougall JD, Tarnopolsky MA. Interaction of fibre type, potentiation and fatigue in human knee extensor muscles. Acta Physiol Scand 2003;178:165-73.
28. Farina D, Cescon C, Merletti R. Influence of anatomical, physical, and detection-system parameters on surface EMG. Biol Cybern 2002;86:445-56.
29. Yoshioka S, Nagano A, Hay D, Fukashiro S. The effect of bilateral asymmetry of muscle strength on the height of squat jump: a computer simulation study. J Sports Sci 2011;29:209-18.
30. Bennell K, Wajswelner H, Lew P, Schall-Riaucour A, Leslie S, Plant D. Isokinetic strength testing does not predict hamstring injury in Australian rules footballers. Br J Sports Med 1998;32:309-14.
31. Bryant AL, Kelly J, Hobmann E. Neuromuscular adaptations and correlates of knee functionality following ACL reconstruction. J Orthop Res 2008;26:126-35.
32. Croisier JL, Forthomme B, Namurois MH, Vanderthommen M, Crielaard JM. Hamstring muscle strain recurrence and strength performance disorders. Am J Sports Med 2002;30:199-203.
33. Hewett TE, Linderfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes: A prospective study. Am J Sports Med 1999;27:699-706.
34. Myer GD, Ford KR, Hewett TE. Methodological approaches and rationale for training to prevent anterior cruciate ligament injuries in female athletes. Scand J Med Sci Sports 2004;14:275-85.
35. Newton RU, Gerber A, Nimphius S, Shim JK, Doan BK, Robertson M. Determination of functional strength imbalance of the lower extremities. J Strength Cond Res 2006;20:971-7.
36. Paterno MV, Ford KR, Myer GD, Heyl R, Hewett TE. Limb asymmetries in landing and jumping 2 years following anterior cruciate ligament reconstruction. Clin J Sports Med 2007;17:258-62.