

# Determinant factors of efficiency when the Counter Movement Jump is performed in acute fatigue

## *Determinantes do desempenho quando o Counter Movement Jump é realizado em fadiga aguda*

Gustavo Bermudez<sup>1</sup>  
Gabriel Fábrika<sup>1,2</sup>

**Abstract** – This work analysed the changes that occur in kinetic-temporal parameters and the electromyographic activity of lower limb muscles during the performance of maximum Counter Movement Jumps (CMJ) done with and without muscular fatigue, to explain the changes in performance in both situations. The vertical strength of fifty jumps performed by ten male sportsmen before and after a fatigue protocol was registered. Records of surface electromyography were obtained for six lower limb muscles; in addition, activation level and intermuscular coordination were analysed. For analysis purposes, negative and positive mechanic working times were considered separately. In both conditions, the temporal course of strength distribution is more important for the performance than any other instantaneous parameter. The negative external working time was significantly lower in fatigue conditions. The electromyographic analysis showed an increase in the activation level of all muscles studied and significant changes in the activation sequence. The specific kinetic-temporal variables were not good predictors of jump height. When CMJ is performed without muscle fatigue, a high value of active state favours the positive work. During fatigue, there could be a partial compensation of the performance due to the increasing activity of the contractile elements, although the activation sequence undergoes significant changes. Thus, the changes in performance would be mainly associated with the decrease in the capacity to transmit power in the proximal-distal direction.

**Key words:** Jump; Muscle fatigue; Muscle strength; Plyometric exercise.

**Resumo** – Este artigo analisa as mudanças que ocorrem na atividade dos parâmetros temporais cinéticos e eletromiográficos de músculos dos membros inferiores, durante a execução do Counter Movement Jumps (CMJ) máximos com e sem fadiga, para explicar os efeitos das mudanças no desempenho, nas duas situações. A força vertical de 50 saltos realizados por 10 atletas do sexo masculino foi registrada antes e depois de um protocolo de fadiga. Foram obtidos registros mediante eletromiografia de superfície para seis músculos dos membros inferiores e foi analisado o nível de ativação e coordenação intermuscular. Para as análises, foram considerados separadamente o tempo de trabalho mecânico negativo e positivo. Nas duas condições, a distribuição de força no tempo é mais importante para o desempenho de qualquer parâmetro instantâneo. O tempo de trabalho externo negativo foi significativamente menor na condição de fadiga. A análise eletromiográfica mostrou um aumento do nível de ativação de todos os músculos examinados e alterações significativas na sequência de ativação. Pode-se concluir que as variáveis cinético-temporais não foram bons indicadores da altura do salto. Quando o CMJ é executado sem fadiga, um alto valor do estado ativo favorece o trabalho positivo. Durante a fadiga, uma compensação parcial do desempenho pode acontecer por aumento da atividade dos elementos contrátil, embora a sequência de ativação sofra alterações significativas. Assim, as alterações no desempenho seriam principalmente, associadas à diminuição da capacidade de transmissão de energia na direção proximal distal.

**Palavras chave:** Exercícios pliométricos; Fadiga muscular; Força muscular; Salto.

1 Universidad de la Republica, Facultad de Medicina, Unidad de Investigación en Biomecánica de la Locomoción Humana, Montevideo, Uruguay.

2 Universidad de la Republica, Facultad de Medicina, Departamento de Biofísica, Montevideo Uruguay.

Received: 17 January 2013  
Accepted: 21 August 2013



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## INTRODUCTION

Counter Movement Jump (CMJ) is among vertical jumps commonly used in evaluations<sup>1</sup>. The presence of eccentric phase for leg extensors considering the jump allows achieving greater height, which is associated with different aspects. Among them, stored elastic energy<sup>2,3</sup>, increased prior activation<sup>4</sup> and the contribution of the stretching reflection<sup>5</sup> stand out.

Several biomechanical approaches such as simulations<sup>6</sup>, electromyographic tests<sup>7</sup> and force platforms<sup>8,9</sup> have been used to identify factors associated with changes in performance during CMJ. All of these approaches resulted in a greater or less useful measure. However, the same vertical force curve results in the same performance, which does not occur with other variables<sup>8</sup>.

A recent study confirmed that the height in CMJ, considered the primary indicator of performance, is related to the maximum normalized force, confirming previous studies on Squat Jump and CMJ<sup>10-13</sup>.

It must be considered that records from force platforms have fundamental information for the study of performance on jumps and do not add data regarding the main causes that determine performance changes. This is the way that combined measures of variables arising from force platforms and electromyography activity (EMG) of muscles involved during the different phases of CMJ could help to better understand the factors that determine performance (height reached in a jump).

Although in real conditions jumps are performed with a degree of muscle fatigue, CMJ studies usually do not include this condition.

It is well established that acute fatigue determines changes in metabolic level<sup>14,15</sup> and that these changes may contribute to decrease capacity by changing the success-contraction coupling process<sup>15</sup> or the reduction of sensitivity in the stretching reflex<sup>16</sup>. Thus, it is possible that fatigue affects the whole jump dynamics during the boost phase. This difference may be associated with the fatigue condition, the degree of activity and the force capacity of contractile elements that may change significantly<sup>15,16</sup>.

The aim of this study was to identify the kinetic-temporal and electromyographic parameters that allow discussing the changes in CMJ performance when these are performed with fatigue. For this, the vertical force curve is analyzed during periods of electromechanical events corresponding to different time during the jump and electromyographic signals from six muscles of the lower limb of 10 athletes. It was observed that the time course of force is a parameter more important than any other in both conditions, the time of negative work decreases significantly in fatigue and changes occur both in the level and sequence of activation of muscle associated with fatigue.

## METHODS

### Characteristics of the sample subjects

A population of ten male athletes (age  $23.5 \pm 3.0$  years, body mass  $72.3 \pm 4.1$  kg, height  $1.75 \pm 0.09$  m) was studied. Inclusion criteria were individuals who train more than three times per week with a maximum of 30 km of jogging per week and rely on previous experience in vertical jumping test. In addition, exclusion criterion was not presenting lesions in the last year. Of selected individuals, six practiced amateur soccer and four middle-distance running (two professionals). An intentional non-probabilistic selection was used given the similarity of training among athletes in order to maintain sample homogeneity and to fulfill the proposed overall objective of this study.

All subjects signed the informed consent form containing clarifications approved by the Ethics Research Committee of the Faculty of Medicine, University of Uruguay (Process No. 071140-001764-09).

### Experimental Protocol

Each subject was instructed to perform five maximum CMJ in each of two conditions fatigue (F) and no fatigue (NF), performing a total of 50 jumps at each condition. During the execution of jumps, the subjects were in the upright position and performed a counter-movement to reach an angle of  $90^\circ$  of knee flexion. The angular variation during jumps was controlled by kinematics, discarding those whose knee flexion varied over  $5^\circ$  in relation to the reference angle.

Fatigue condition was obtained by performing 1 minute of continuous jumping quantified by the drop in average power analyzed in periods of 15 seconds<sup>17</sup>.

Jumps were performed on a force platform (AMTI OR6-5) (Advanced Mechanical Technology Inc., Watertown, Massachusetts) while the electrical activity of the rectus femoris (RF), vastus lateralis (VL), biceps femoris (BF), tibialis anterior (TA), medial gastrocnemius (GM) and Soleus (SOL) muscles was synchronously recorded by surface electromyography

EMG recordings were made with two Miotec® electromyography devices (Miotool 400) and Miograph® 2.0 software with acquisition rate of 1000 Hz and yield of 1600 per channel. Disposable surface electrodes (Kendall MEDI-TRACE-100 Ag / AgCl) are used in a bipolar configuration with a separation of 2 cm from center to center. The electrodes were located in the muscles of the right leg according to criteria established in<sup>18</sup>. For the purposes of standardizing electromyographic recordings, recordings were performed during maximal voluntary contractions (MVC) for 5 s.

## Data processing

Only the vertical component ( $F_y$ ) of force curves obtained from the force platform was analyzed. The records were exported by MATLAB® and filtered through a third-order Butterworth filter with maximum frequency determined by the residues method of Winter<sup>19</sup>.

Jump height ( $H_{max}$ ) was calculated as:

$$H_{max} = V_v^2 \cdot (2g)^{-1}$$

where  $g$  is the gravity acceleration ( $9.81 \text{ m / s}^2$ ) and  $V_v$  is the vertical velocity of the subject's center of mass (CM), which was determined considering the time of flight ( $T_{air}$ ) directly obtained from the  $F_e$  curve<sup>17</sup>:

$$V_v = \frac{1}{2} \cdot T_{air} \cdot g$$

The support time of the  $F_y$  curve was divided into two parts, the descending phase (T1) and the ascending phase (T2) of the CM at each jump.

Besides the value of the maximum vertical force ( $F_{max}$ ), impulses (integral of the closed area under the  $F_e$ -time curve) for T1 ( $Imp_1$ ) and T2 ( $Imp_2$ ) in each condition were calculated.

The EMG signals captured were filtered with a 3<sup>rd</sup> order Butterworth filter between 10 and 500 Hz and were synchronized with the corresponding records of vertical force ( $F_y$ ) considering an electromechanical delay of  $0.012 \text{ s}^5$ . The records were analyzed in the time domain by calculating by the root mean square (RMS) values using a temporal window of  $0.25 \text{ s}^7$ .

To evaluate the coordination and the activation level of the RMS values, they were divided into time periods T1 and T2.

The level of activity of each muscle was quantified by calculating the integral of RMS. The values obtained during T1 and T2 for the different muscles were normalized by dividing them by the length of the interval and the maximum RMS value obtained during MVC, thus obtaining values of integral relative to T1 and T2. The effects that results in activation amplitude obtained in this study were comparable to those in literature<sup>7,20</sup>, and the values of each muscle varied for each subject and condition.

To study the relative differences in the activation sequence, we considered the moment in which the maximum RMS value normalized with respect to T1 and T2. This procedure was performed for each muscles analyzed in each condition.

## Data Analysis

For each series of jumps, mean and standard deviation were calculated for all variables, evaluating the data fitting through the normal distribution by Shapiro-Wilk test and homogeneity was tested by the Levene test.

Pearson correlation test was performed between each kinetic-temporal variable and jump height in each condition.

The difference in T1, T2, Fmax, IMP1, Imp2 was quantified and the level of activation by “t” test for averages compared between values obtained in F and NF condition for each time interval. ( $p < 0.05$ ).

For the analysis of activation sequence, the time of maximum activation was measured for each subject and the change between conditions by “t” test for comparison measures was verified ( $p < 0.05$ ).

All statistical analyses were performed with the SPSS 13.0 software (Statistical Package for the Social Sciences, Sun Microsystems, USA).

## RESULTS

The heights reached in NF ( $0.31 \pm 0.06$  m) and F ( $0.29 \pm 0.06$  m) were significantly different ( $p < 0.05$ ). Table 1 shows the results obtained in the force platform in each condition, while Tables 2 and 3 show the results of the electromyographic analysis.

**Table 1.** Values (mean and standard deviation) of variables analyzed from records of vertical force in fatigue (F) and no fatigue (NF) conditions

	T1(s)(†)	T2(s)	F <sub>max</sub> (N)	Imp <sub>1</sub> (N.s)	Imp <sub>2</sub> (N.s)
F	0.49±0.06	0.25±0.06	1700±162	179±21.5*	155±45*
NF	0.54±0.07	0.24±0.05*	1733±144*	177±21.2	168±45

(\*) indicate those cases in which significant correlation of maximum force (Fmax), time of descending phase (T1), time of ascending phase (T2), impulse during T1 (IMP1) and during T2 (Imp 2), jump height (\*  $p < 0.05$ ) was found. (†) indicates the presence of significant differences for the same variable between conditions.

**Table 2.** Results of the integral of RMS of muscles studied in fatigue (F) and no fatigue (NF) conditions over two periods of analysis.

time	muscle	NF	F	time	muscle	NF	F
T1	BF*	0.106	0.116	T2	BF*	0.142	0.234
	RF*	0.423	0.459		RF*	0.481	0.764
	VL*	0.103	0.124		VL*	0.197	0.221
	TA*	0.100	0.147		TA*	0.112	0.174
	GM*	0.198	0.236		GM*	0.301	0.453
	SOL*	0.112	0.255		SOL*	0.104	0.142

Biceps femoris (BF), rectus femoris (RF), vastus lateralis (VL), tibialis anterior (TA), medial gastrocnemius (GM) and soleus (SOL). Results of the “t” test for compared measures before and after fatigue in two time periods analyzed are included. (\*) indicate significant difference ( $p < 0.05$ ).

**Table 3.** Results for the relative time of the peak activity of muscles analyzed before and after the fatigue protocol in two time periods analyzed.

time	muscle	NF	F	time	muscle	NF	F
T1	BF	98.6	98.2	T2	BF*	67.9	46.2
	RF*	94.1	96.3		RF*	32.7	7.6
	VL	17.1	17		VL*	16.8	18.8
	TA	60.3	56		TA	20.6	18.7
	GM*	51.9	76.3		GM*	77.5	25.1
	SOL*	49.5	60.4		SOL*	78.3	42.4

Biceps femoris (BF), rectus femoris (RF), vastus lateralis (VL), tibialis anterior (TA), medial gastrocnemius (GM) and soleus (SOL). Results of the "t" test for compared measures before and after fatigue in two time periods analyzed are included. (\*) indicate significant difference ( $p < 0.05$ ).

## DISCUSSION

The height achieved in CMJ without fatigue ( $0.31 \pm 0.06$  m) and with fatigue ( $0.29 \pm 0.06$  m) was comparable to that reported in other studies, in which subjects jumped using an equivalent technique<sup>7</sup>.

The record of maximum vertical force (Fmax) is the first result to be observed, as it was solely associated with the height achieved when the jumps are performed in the absence of fatigue. Whereas in real conditions vertical jumps are performed with a degree of muscle fatigue, this result reports that Fmax cannot be considered a good predictor of performance on CMJ.

Previous studies have associated the decreased performance in the condition with fatigue to changes in the capacity of different muscle groups<sup>7</sup>. These changes can assign the combined effect of the capacity of utilization of elastic energy and change in contractile activity<sup>4,21</sup>, and this information may vary for each muscle group considered<sup>7</sup>.

In general, our results showed that the kinetic-temporal variable correlated with jump height change in each condition (Table 1). The significant correlations of T2 with height in condition NF corroborate reports of a similar experimental study where eighteen variables defined from the record of vertical force were analyzed<sup>8</sup>. On the other hand, it was observed that in the fatigue condition, there are no correlations of time of each phase with jump height. The correlations of times found would indicate that without fatigue determines that the performance on CMJ occurs is a positive work phase and that with fatigue, this situation changes.

The results of t-test showed that there is a marked decrease in T1 (negative work time) when CMJ is carried out with fatigue. This is consistent with the fact that F max is not a determining factor in fatigue, in the sense that the maximum vertical force that the subject performs against the floor is observed just before the moment that this condition changes.

The values found correlating impulse with height in different periods in fatigue support the idea that in ballistic movements, performance is

based on optimizing the impulse and not necessarily in any instantaneous value of force or power<sup>8</sup>, i.e., in the form of the vertical force curve. This form of force curve during early negative work would be determined by the participation of contractile elements, which would be determined by both pre-activation as the participation of the stretching reflex, since both aspects influence the force produced during T1<sup>16</sup>.

An increase in the level of activation of all muscles studied was observed (Table 2). Considering these results, it is suggested that during CMJ on condition of fatigue, optimization of force-time product during positive work would be favored by the participation of contractile elements.

Studies conducted to verify the sequence of activation have shown significant changes fundamentally during T2. During this time, a significant delay in the time of maximum peak in RF, BF and GM SOL and a significant advance in the VL could be observed. Changes in bi-articular muscles (RF, BF and GM) may be fundamental as these are determinants of the transmission of power at the distal proximally direction<sup>6</sup>. Advances in peak VI added to changes in RF and BF could reflect an important imbalance in the level of control of the knee joint in relation to fatigue. However, these changes should be considered carefully, since the evaluation of coordination through a value such as activity peak can lead to erroneous interpretations.

The fact that the sample does not allow interference on the general population is among the main limitations of this study, although all statistical tests obtained low error probability. Moreover, this study performed an analysis of the electromyographic signals based on the two most commonly used parameters. These do not yet have a general consensus, by which a more complex analysis of signals may in future add new elements to the discussion.

## CONCLUSION

The results of this study support the idea that the pattern of force distribution in time determines a good performance at CMJ in any condition. By increasing fatigue the contribution given by contractile elements during positive work also increases. On the other hand, the activation sequence is changed so that it is possible that changes in performance are mainly associated with a decrease in the ability to effectively transmit the power in the proximal-distal direction.

## Acknowledgements

The authors thank to personal of LAPEX, *Escola de Educação Física* and athletes of *Sociedade Ginástica de Porto Alegre (SOGIPA)* for their assistance with data collection.

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**Corresponding author**

Gabriel Fábrika  
Departamento de Biofísica, Facultad  
de Medicina (UDELAR)  
Avenida General Flores 2125  
C.P. 11800, Montevideo, Uruguay  
E-mail: cgfabrika@gmail.com