DOI: 10.4025/jphyseduc.v32i1.3232

Artigo Original

RELIABILITY AND SENSITIVITY OF COUNTERMOVEMENT JUMP-DERIVED VARIABLES IN DETECTING DIFFERENT FATIGUE LEVELS

REPRODUTIBILIDADE E SENSIBILIDADE DAS VARIÁVEIS DERIVADAS DO SALTO COM CONTRA MOVIMENTO NA DETECÇÃO DE DIFERENTES NÍVEIS DE FADIGA

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RESUMO
O objetivo foi verificar a reprodutibilidade e a sensibilidade de variáveis derivadas do salto com contra movimento (CMJ) na detecção de pequenas, moderadas e grandes alterações e se a capacidade das variáveis em detectar fadiga é dependente do volume do exercício fatigante. Dezessete homens fisicamente ativos realizaram dois protocolos de fadiga, em semanas separadas, compostos por saltos verticais contínuos: protocolo curto (7 x 10 saltos) e protocolo longo (14 x 10 saltos). A altura do salto (JH), a potência (PO), o impulso (IMP) e a rigidez vertical (K_{VERT}) foram mensurados durante o CMJ antes e imediatamente após os protocolos de fadiga. Foram avaliados o coeficiente de correlação intraclasse, erro típico de medida, mínima mudança valiosa e magnitude baseada em inferência. PO e JH apresentaram excelente reprodutibilidade e boa sensibilidade para detectar pequenas e médias alterações, respectivamente. Os efeitos da fadiga podem ser detectados mais provavelmente pela PO, independentemente do volume de exercício fatigante. JH e IMP parecem ser afetados somente após protocolo longo e K_{VERT} somente após protocolo curto. Em conclusão, PO (pico e média) é o um marcador melhor durante o CMJ com excelente reprodutibilidade e sensibilidade, o que permite detectar até mesmo pequenos efeitos e diferenciar níveis de fadiga.
Palavras-chave: Ciclo alongamento-encurtamento. Potência. Altura do Salto. Impulso. Rigidez vertical.

ABSTRACT
The aim was to verify the reliability and sensitivity of countermovement jump (CMJ) derived variables in detecting small, moderate and large changes and whether the capacity of CMJ-derived variables in detecting fatigue is dependent of the volume of the fatiguing exercise. Seventeen physically active men performed two fatigue protocols, on separate weeks, composed by continuous vertical jumps: short protocol (7 x 10 jumps) and long protocol (14 x 10 jumps). Jump height (JH), power output (PO), impulse (IMP) and vertical stiffness (K_{VERT}) were measured during CMJ prior to and immediately after the fatigue protocols. Intraclass coefficient correlation, typical error, smallest worthwhile change and magnitude-based inference were analyzed. PO and JH presented excellent reliability and good sensitivity to detect small and medium changes, respectively. Negative effects of fatigue could be detected most likely by PO, regardless of fatiguing exercise volume. JH and IMP seem to be affected only after long protocol and K_{VERT} only after short protocol. In conclusion, PO (peak and mean) is the better marker in CMJ with excellent reliability and sensibility, which allows detect even the small effects and differentiate the fatigue levels.
Keywords: Stretch-shortening cycle. Power output. Jump height. Impulse. Vertical stiffness.

Introduction

The assessment of neuromuscular fatigue and muscle recovery of athletes during training or competition is considered a key factor for sports performance[1]. The monitoring of fatigue status allows the trainers to adapt the training program and to minimize the risk of non-functional overreaching and injuries[1,2]. A number of tests have been proposed to monitor neuromuscular fatigue; particularly, field tests such as countermovement jump (CMJ) have been suggested as suitable means of neuromuscular assessment available to practitioners due to their great practicality[3-5].

It is known that effective monitoring requires valid, reliable, and sufficiently sensitive tests to discern the functional changes that will influence performance[4,6]. Great reability is important to ensure that the visualized effect is real and not caused by variation[7]. The CMJ has been considered a reliable and one of the more valid forms of neuromuscular testing due to its similarities with muscular actions involved in athletic performance (i.e., stretch-shortening cycle – SSC)[8,9]. However, there is no consensus about which is the most appropriate and sensitive vertical jump parameter to detect fatigue effects[4]. A test or variable with good sensitivity allows even small changes to be detected[10,11], whether they are improvements or decrements (e.g., fatigue effects).

Traditionally, a number of researchers and professionals have been using the vertical jump height as an objective and practical marker of fatigue[12-14], but they did not elucidate the real capacity of this variable in detecting small changes during training. In a recent meta-analysis, Claudino et al.[5] found that average jump height presented good sensitivity to detect fatigue and supercompensation effects. On the other hand, some recent studies[15] have been pointing that other jump variables, such as power output, may be more sensitive than jump height for determining an athlete's neuromuscular status. This may occur because during fatiguing exercise, changes in power output are observed first in an attempt to maintain jump performance (i.e., jump height)[16].

It is known that SSC fatigue induces acute and delayed alterations on task performance (e.g., jump height or power output) due to loss of strength, but it also has effect on proprioceptive and neuromuscular level, changing the ability of shock absorption by the muscles[17,18]. In these situations, parameters of movement such as lower limb stiffness may be a sensitive marker of fatigue. It is important to highlight that previous investigations have been reporting conflicting findings about sensitivity, probably because fatigue is task dependent[19]. Consequently, the capacity of a marker to detect fatigue may be dependent on aspects such as volume and/or intensity of the fatiguing exercise.

Based on these assumptions, the first objective of present study was to verify the reliability and sensitivity of CMJ-derived variables (jump height, power output, impulse and stiffness) in detecting small, moderate and large changes. Additionally, we aimed to verify whether the capacity of CMJ-derived variables in detecting fatigue is dependent of the volume of the fatiguing exercise.

Methods

Participants

Seventeen health men (age: 26.8 ± 3.3 years, body mass: 79.3 ± 11.5 kg, height: 181.2 ± 6.4 cm, body fat percentage: 13.2 ± 4.4%) volunteered to participate of this study. The participants were considered physically active, practitioners of physical exercises (strength training, running and/or sports involving jumps) three to five times a week, for at least one year. Participants were asked not to perform physical exercises involving the lower limbs 24h prior to the test sessions and to avoid caffeine intake six hours prior to testing. All participant signed a consent, approved by the local ethics committee, agreeing to participate on this research. All participants signed an informed consent form approved by the local ethics and human research committee (2.676.183).

Experimental Procedures

Participants performed two fatigue protocols using continuous vertical jumps (A – lower volume; B – higher volume). Dependent variables (jump height, power output, net impulse and vertical stiffness) were measured in the countermovement jump (CMJ) prior to and immediately following the fatigue protocols. These kinect parameters were choosen because their relevance to the jump performance. The same group performed both protocols, i.e. protocol A followed by protocol B, separated by a one-week interval. The reliability and sensitivity of CMJ-derived variables were measured confronting the values at two pre-fatigue conditions.

In an inicial separated session, participants were familiarized with the CMJ, getting approval from an avaliator in relation to the movement pattern. The participants returned in another day (at least 24h later) to performe the the first fatigue protocol. Before the CMJ assessment participants performed ten minutes on a cycloergometer at 90W as warm-up. After, the participants performed three CMJ with maximal effort in pre-fatigue condition (baseline) on two force platforms (AMTI® OR6-7-OP-2000, United States - 2000 Hz), one foot on each. The jumps started from a static standing position, then they should perform a countermovement (descent phase) followed by a rapid and vigorous extension of the lower limb (ascent phase). Participants were asked to maintain their trunk as vertical as possible, with hands on the hips, and with knee angle approximately at 90° at the end of descent phase of the movement. Three-dimensional (3D) kinematics of CMJ were obtained using a system with eight high-speed integrated cameras (VICON®, MX systems, Oxford MetricsGroup, UK - 200Hz), accordingly calibrated. Reflective markers (14mm) were placed on the anatomic point of major trochanter in the right side of the body for kinematic analysis.

After the measurements of baseline condition, the participants executed the fatigue protocols (short protocol first followed by long protocol one week later). Immediately after, the participants performed again three maximal CMJ in the post-fatigue condition and respond the RPE scale referring to the total effort applied to perform the fatigue protocol.

Fatigue protocol

The fatigue protocols were executed on a piezoelectric force platform (Kistler® Quattro Jump, 9290 AD, Switzerland - 500Hz). Aiming to induce different fatigue levels, two fatigue protocols composed by vertical jumps were performed one-week apart. Each fatigue protocol had a different volume: Short protocol (ST) consisted of seven sets of 10 continuous jumps, and long protocol (LG) consisted of 14 sets of 10 continuous jumps, with one minute interval between bouts. The ST was performed first to minimize the possible fatigue of the first protocol on the second one[12]. The participants received verbal encouragement to perform all the jumps with the maximum intensity. To verify the percentage decrease in jump performance during the protocol the fatigue index was calculated through equation: $((P_{MEAN\_4J} – P_{MEAN\_end4J}) / P_{MEAN\_4J})$ x 100[18], where, P_{MEAN_4J}, average power of the first four jumps, and P_{MEAN_end4J}, average power of the last four jumps.

Data analysis and dependent variables

From the three CMJ performed pre and post-protocols, it was exluded that with greater variation in jump height. The average of the two remaining jumps was used for analysis. From 3D-reconstruction of CMJ movement, the coordinates of the reflective marker of trochanter were obtained and then filtered using a fourth-order Butterworth low-pass filter with a cut-off frequency of 10 Hz, determined from spectral analysis. The jump height (JH) during CMJ was considered the highest vertical displacement of the reflective marker of trochanter[20]. This method is validated and considered the “gold standard” for jump height measurement[20,21].

Ground reaction force (GRF) data was obtained during the CMJ from the force plates. GRF were filtered using a low-pass, fourth-order Butterworth filter with a cut-off frequency of 10 Hz, determined from spectral analysis. The GRF was integrated for obtaining the CMJ-derived variables. First, acceleration curve was obtained by dividing the GRF values by the subjects' body mass; then, the velocity curve was obtained by integrating the acceleration curve[22]. Power output was calculated by multiplying the GRF by the velocity in the positive phase of the CMJ. The peak power is considered the highest value in the power output curve, while the mean power is the mean value of the curve[22]. Impulse was calculated during the positive phase of CMJ, through the integration of GRF in time. The impulse was divided by the subjects' body mass for determining the net vertical impulse[23].

Vertical stiffness (K_{VERT}) was determined dividing the peak GRF by vertical displacement of center of mass (ΔY) during the landing phase of CMJ[24]. The peak GRF was obtained from the force plates and the ΔY was determined by double integration of GRF. All the data analysis was made through a specific algorithm implemented in the MATLAB® software.

Statistical Analysis

Data were described as means and standard deviations (SD). The Intraclass Correlation Coefficient (ICC) was calculated to assess the reliability of CMJ-derived variables at two pre-fatigue conditions. The ICC values were classified according to Fleiss (1986): > 0.75 are classified as “excellent”; 0.40–0.75 as “fair-to-good”; and < 0.40 as “poor”. To test the sensitivity of vertical jump-derived variables we calculated the typical error (TE) (standard deviation of differences divided by the √2) with 95% confidence interval and the smallest worthwhile change (SWC). The SWC was obtained by multiplying the between-subject SD by 0.2, 0.6 and 1.2 (small, medium, and large effect, respectively), and the usefulness of each variable was assessed by visual comparison of SWC scores with the TE[11]. Thus, if the TE was higher than SWC, the effect was considered “marginal”; a TE similar to the SWC was considered “medium”; and a TE less than the SWC was considered “good” for detecting small, medium, and large differences, respectively[11].

Additionally, magnitude-based inference analysis was used to examine practical significance (effects) of different fatigue protocols (short and long) on CMJ-derived variables. The magnitude of differences between pre and post protocols in both conditions (short and long protocol) was calculated and expressed as standardized mean differences with 90% of confidence limits. The chances that the true (unknown) mean changes were experienced negative or positive effects (i.e. greater than the SWC [0.2 multiplied by between-participants SD]) and trivial, were determined. Quantitative chances of negative or positive effects were assessed qualitatively, as follows: <1% = most unlikely, 1–5% = very unlikely, 5–25% = unlikely, 25–75% = possibly, 75–95% = likely, 95–99.5% = very likely, and >99.5% = most likely. If the chances of negative and positive effects were both > 5%, thus the true difference was assessed as unclear[25].

Results

Table 1 shows the reliability and sensitivity of measures of vertical jump-derived variables (jump height, power output and impulse) in baseline condition. The ICC values were considered excellent for jump height and power output (peak and mean), and fair-to-good for impulse and K_{VERT}. The $SWC^{0.2}$ was higher than TE only for mean and peak power output and close to jump height ($SWC^{0.6}$ > TE). For impulse and K_{VERT} only the $SWC^{1.2}$ was higher than TE.

Table 1. Reliability and sensitivity measures of vertical jump-derived variables obtained during baseline condition

	Pre_1	Pre_2	ICC (95% CI)	TE (95% CI)	$SWC^{0.2}$	$SWC^{0.6}$	$SWC^{1.2}$
Jump height (cm)	48.6±6.9	49.1±6.3	0.98 (0.90-0.99)	1.39 (1.03-2.11)	1.31	3.94	7.89
Peak power (W/kg)	53.4±7.2	52.6±6.8	0.97 (0.91-0.99)	1.34 (1.00-2.04)	1.41	4.22	8.44
Mean power (W/kg)	27.5±3.6	27.2±3.4	0.97 (0.91-0.99)	0.69 (0.51-1.05)	0.70	2.11	4.22
Impulse (N.s)	4.0±0.4	4.1±0.3	0.55 (0.10-0.81)	0.25 (0.19-0.36)	0.07	0.22	0.44
K_{VERT} (kN/m)	9.3±4.2	8.0±2.6	0.51 (0.06-0.79)	2.51 (1.87-3.82)	0.70	2.10	4.20

Note: K_{VERT} = vertical stiffness, ICC = Intraclass Correlation Coefficient; TE = typical error 95% confidence interval (CI); SWC = smallest worthwhile change (0.2, 0.6 and 1.2 – small, medium and large effect sizes, respectively)
Source: Authors

Both protocols induce fatigue (ST = 15.8%; LG = 27.0%). Table 2 summarizes the values of pre and post fatigue protocols (short and long) and magnitude-based inferences for vertical jump-derived variables. We verified that power output (mean and peak) showed very-likely to most-likely negative effect for both short and long fatigue protocols; whereas jump height and impulse showed most-likely negative effect only for long fatigue protocol and K_{VERT} presented likely negative effect for short protocol.

Table 2. Changes in the vertical jump-derived variables after ST and LG fatigue protocols and qualitative inferences about the effects on performance

	Protocol	Pre	Post	Δ	SCM 90% CI	Qualitative inference
JH (cm)	ST	48.6±6.8	46.6±6.1	2.0	-0.28 (-0.47 to -0.08)	74/26/0 Possible negative
	LG	49.1±6.3	43.4±7.1	5.7	-0.86 (-1.21 to -0.52)	100/0/0 Most likely negative
PPO (W/kg)	ST	53.4±7.2	49.6±6.6	3.8	-0.51 (-0.66 to -0.36)	100/0/0 Most likely negative
	LG	52.6±6.8	48.6±6.8	4.0	-0.56 (-0.82 to -0.29)	98/2/0 Very likely negative
MPO (W/kg)	ST	27.5±3.6	25.6±3.3	1.9	-0.51 (-0.66 to -0.36)	100/0/0 Most likely negative
	LG	27.2±3.4	25.1±3.5	2.1	-0.59 (-0.86 to -0.32)	99/1/0 Very likely negative
VI (N.s)	ST	3.96±0.45	3.97±0.34	0.1	0.0 (-0.39 to 0.38)	19/62/19 Unclear
	LG	4.14±0.26	3.72±0.57	0.4	-1.53 (-2.22 to -0.84)	100/0/0 Most likely negative
K_{VERT} (kN/m)	ST	9.33±4.19	7.71±2.75	1.6	-0.37 (-0.68 to -0.06)	82/18/0 Likely negative
	LG	8.00±2.64	7.51±3.13	0.5	-0.18 (-0.51 to 0.16)	45/52/3 Possible negative

Note: JH: jump height; PPO and MPO: peak and mean power output; VI: vertical impulse; Kvert: vertical stiffness;SCM: standardized change in mean, CI: confidence interval
Source: Authors

Discussion

This study aimed to test the reliability and sensitivity of CMJ-derived variables in detecting small, moderate and large changes, as well as to verify the capacity of these variables in detecting different effects of fatigue levels. The main results showed that power output (mean and peak) and jump height presented excellent reliability and good sensitivity to detect small and medium changes, respectively. In addition, fatigue effects were detected most likely by power output irrespective of fatiguing exercise volume (short or long). Jump height and impulse seem to be affected (most likely negative) only when longest fatigue protocol was applied. K_{VERT} seems to be very affected by fatigue only after short protocol (likely negative).

In the vertical jump assessment, mechanical power output is considered the most direct indicator of lower limb muscle power capability[26,27]. In our study, we verified that power output (peak and mean) showed to be reliable and the most sensitive markers compared to other vertical jump parameters, being able to detect even small changes in performance. The low variability in power output can explain its high reliability. In addition, the high sensitivity of this variable can be attributed to the low typical error of measurement found. We observed that typical error was lower than $SWC^{0.2}$, i.e. the smallest changes can be considered as real, making the variable more sensitive[11]. Other studies have also found good/excellent CMJ power output reliability[4,28,29]. Roe et al.[29], for example, found good sensitivity for power output.

The jump height also showed excellent reliability; however, medium sensitivity to detect performance changes was reported. The reliability and sensitivity of CMJ jump height had already been demonstrated and discussed previously[4,8,28,30,31]. Roe et al.[29] also verified good reliability but low sensitivity of jump height. It is suggest that the high reliability of jump height is due to the motor pattern required for the vertical jump movement is habitual for the participants, thus the CMJ strategy (motor patterns) and output (final result) remains relatively stable[8]. The technical way of measuring the jump height through the video analysis (as in the current study), is considered a gold standard, and may also have contributed to the great reliability observed[20,21]. According to our results and previous studies, jump height seems to present less sensitivity than power output. Thus, if a force plate is not available for coaches or physical trainers, power output can be calculated from jump height by using equations, such as from Samozino et al.[32] may be an interesting alternative. This method shows acceptable errors and bias and allows reliable and practical computation of push-off averaged force and velocity outputs[33]. However, the sensitivity of estimated power output from jump height has not yet been tested.

Net vertical impulse and K_{VERT} showed moderate reliability and poor sensitivity, allowing to detect only large changes. These variables presented large variability, leading the typical error of measurement to increase substantially. High variability associated with a considerable typical error do not allow identifying if small or medium changes observed are real[11]. It can be speculated that changes in motor pattern for the maintenance or achievement the performance are related to the great variability found for these variables. These changes or compensations can, for example, make the movement more or less stiff, as well as prolong or shorten the time of force application on the ground, which would directly affect the impulse. Previous studies verified good values of reliability for both impulse[4,34,31] and K_{VERT}[35], which is in contrast to our results. This discrepancy and the low sensitivity found for these variables in the present study suggest that impulse and K_{VERT} are vertical jump markers that should be used carefully when the objective is identify changes in performance.

The high mechanical stress produced by the SSC actions induces muscle fatigue, leading to impairment in muscle function, and represented by the decrease in variables related to the jump performance[9]. Considering the K_{VERT}, the decrease is suggested by the reduction in the pre-activation of the sural triceps and knee extensors muscles[36,37] and changes in the stretching reflex[18,37], which may affect the movement braking capacity. When analyzing if the CMJ variables can detect different fatigue levels, it was verified that all CMJ-derived variables were affected by the fatigue protocols in high or less magnitude, with exception of impulse in short protocol (unclear inference).

Muscle fatigue is progressive and task-dependent[18], i.e. fatiguing exercise volume is related to the magnitude of the observed losses. Nicol, Avela and Komi[9] suggest that more intense or longer exercises cause greater damage to muscle function. This corroborates the findings of the present study. The power output (peak and mean) were the variables most affected by fatigue, decreasing (most likely and very likely, respectively) after both protocols (short and long), but with more emphasis after the longest protocol. Thus, it can be observed that the power output is capable of detecting negative effects of fatigue regardless of volume of exercise, being able even to differentiate these effects between the volumes. Gathercole et al.[4] investigated the effect of fatigue on CMJ-derived variables, with aim of determining which kind of jump would be most sensitive to detect fatigue, and also found that power was more affected by fatigue than jump height.

Jump height and impulse suffered similar effects (most likely), but only after long protocol. It is known that jump height is strongly related to the impulse[22], then, it is not surprising that the effects of fatigue were similar in these variables. However, the ability of jump height and impulse to detect fatigue is dependent of the volume of exercise. It seems that low levels of fatigue (below 15% decrement) cannot be detected by jump height and impulse, indicating that these variables are capable of differentiate only high fatigue levels (from 27% decrement). Rowell et al.[15] recently conducted a study for investigated the sensitivity of jump height to performance changes in different load matches in football players. The authors concluded that the jump height suffered significant decreases after medium and large load matches, exhibiting a dose-response pattern. Jump height was not sensitive enough to detect changes after low load match, find similar to the present study.

K_{VERT} was the variable less affected by fatigue, causing only likely negative effects and only after the short protocol. It seems that K_{VERT} depend on exercise volume for detection of fatigue, but the capacity of differentiates fatigue levels is controversy. Why K_{VERT} was affected only after the short protocol remains unclear. It can be speculated that after long protocol, changes in the coordination pattern may appear due to high fatigue levels, which ensure the maintenance of stiffness values similar to basal ones[38,39].

One possible limitation of the present study is that the post-fatigue assessments were performed, on average, 1 minute and 20 seconds after the end of the protocol. This time of recovery may possibly have contributed to minimize the observed effects of fatigue.

Conclusion and practical applications

In conclusion, peak and mean power output seem to be the best variables of CMJ for detecting changes, since they showed excellent reliability and sensitivity. In addition, power output was able to detect the fatigue effects irrespective of volume of exercise. Jump height showed excellent reliability and medium sensibility to detect changes in performance, besides it was able to detect fatigue effects when long fatigue protocol was performed. Impulse and K_{VERT} showed low reliability and sensitivity. Impulse was able to detect the effects of fatigue after higher fatigue levels, while K_{VERT} only after low fatigue levels.

It has been a concern of coaches and researchers to find reliable tests and markers for training monitoring. Our results indicate that power output and jump height from CMJ are reliable variables, but is the first may be considered a more sensitive variable, being able to detect different fatigue levels. In addition, when the power output cannot be obtained directly from force platforms, we suggest using Samozino method[33] to calculate jump power from jump height (obtained by using contact mat, for example)[34]. However, future studies should focus in the sensitivity analysis of this method to identify performance changes.

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Acknowledgment: The authors thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)

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Received on Oct, 10, 19.
Reviewed on Apr, 27, 20.
Accepted on Apr, 28, 20.

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