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Original Research

Acute fatigue in endurance athletes: The association between countermovement jump variables and creatine kinase response.

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Abstract: The purpose of this study was to determine the variables of acute neuromuscular fatigue (NMF) and its correlation with the serum concentration of creatine kinase (CK) pre- and post-training through performance analysis counter movement jump (CMJ). **Methods:** Eight male endurance performance athletes performed 3 trials CMJ in force platform before and after fatigue protocol high intensity intermittent running (PFAI) (fatiguing to the maximum possible rate of work for each repetition Protocol). A total of 8 variables were analyzed through CMJ and the biomarker CK before and after fatigue protocol. **Results:** No significant differences for the variables of mean force MF (P = 0,62. d = 0,03), time to peak force TTPF (P = 0,46. d = 0,43), jump height JH (P = 0,19. d = 0,65), flight time FT (P = 0,26. d = 0,58), relation flight time: contraction time FT: CT (P = 0,74. d = 0,59) and CK (P = 0,79. d = 0,31). Significant differences in variables of peak power (p = 0.008. d = 1,37) and contraction time (p = 0.01. d = 0,76) were found. Finally, Spearman's correlation (Spearman's Rho) for non-parametric tests was performed between peak power (PP) (p = 0.002) (r = 0.92) and contraction time (CT) (p = 0.001) (r = 0.97). **Conclusions:** There is a neuromuscular fatigue state in the acute phase determined of CMJ variables, independent of lineal relation CK production. Likewise, it is highlighted a major parameter the reduction of peak power and increment of contraction time in the neuromuscular performance.

Keywords: runners, neuromuscular fatigue, monitoring athletes, biomarker.

1. Introduction

The development of peripheral neuromuscular fatigue is defined as progressive depending on the intensity and duration of the exercise performed (Enoka and Stuart, 1992) therefore, the appearance of such fatigue is related to decrease in the ability to produce force added to muscle damage (microinjury)" (Alba-Jiménez et al., 2022; Gruet et al., 2013; Wan et al., 2017). The overwhelming sense of lack of energy, exhaustion and tiredness, relates to a difficulty keeping performance in several sport modalities, moreover thermoregulation and depletion of glycogen stores (Enoka & Duchateau, 2016; Thomas et al., 2018).

Within the sports field, neuromuscular fatigue is an important issue as it evidences several changes in the physiological processes of the body related to skeletal muscle, due to the accumulation of metabolic residual products produced by the increase of inorganic phosphate (Pi) and the reduction of excitability contributes to a minor in the release of calcium by the sarcoplasmic reticulum and the consequent decrease in the strength of muscle contraction. (Lindinger MI. 2006). First, it is important to note that alterations in the concentration of, hydrogen ions (H+), calcium ions (Ca2+), and potassium (K+) are related to fatigue (McKenna et al., 2008; Tornero-Aguilera et al., 2022a). Therefore, the regulation of this ionic state becomes critical for muscle membrane excitation, contraction and energy metabolism (Allen et al., 2008). Secondly, studies have shown that by generating alterations in the excitation and efficiency of neuromuscular transmission (peripheral fatigue), there is a decrease in the maximum voluntary contraction at the time of exercise or sports competition. (Gandevia, 2001).

It is also necessary to indicate that the serum level of skeletal muscle enzymes is a functional marker of state muscle tissue. An increase in these enzymes can represent not only a rate of cell necrosis but also secondary tissue damage with acute and chronic effects from intense exercise. Changes in serum enzyme and isoenzyme levels are also found in normal subjects and in athletes after vigorous exercise. The enzymatic amount generated by muscle activity through CK shows the demand on muscle fibers according to the duration and intensity of training (Alba-Jiménez et al., 2022; Brancaccio et al., 2007; Lehmann et al., 1993; Wu et al., 2019)

Furthermore, the muscle activation and contractile function seems to be the most relevant factors for performance fatigability. In particular, prolonged fatigue originates at the neuromuscular level while short-term has a metabolic origin (Wu et al., 2019). Thus, the relationship between CK (Edwards et al., 2018) and CMJ test variables (Claudino et al., 2017) has been used as evidence of increased catabolic activity during periods with high training loads, indicating increases over markers of overreaching (Cormack, Newton, & McGuigan, 2008) and the muscle damage in a fatigue-monitoring, therefore it is essential to determine the neuromuscular performance status, more than CK levels in the blood, due to the neuromuscular origin of fatigue.

Indeed, the increase in CK following the running session, suggests that eccentric contractions associated with high-speed movements still play a role in the muscle damage response and therefore an accentuated change in blood CK (Hagstrom & Shorter, 2018) related to CMJ variables (peak power, contraction time, ratio flight time – contraction time) (Marqués-Jiménez et al., 2022; Philipp et al., 2023; Theofilidis et al., 2018). Nonetheless, it is clear that high intensity running session could causes substantial increases in blood CK and changes of velocity and muscle action, indicative of skeletal muscle damage.

Finally, the evaluation and measurement of neuromuscular fatigue could be performed by means of technological tools that record the CMJ performance variables (Gathercole et al., 2015). This project aims to determine the variables of NMF and its correlation with the serum concentration of CK through performance analysis CMJ of endurance athletes.

2. Materials and Methods

Participants – A total of eight male performance athletes volunteered for this study. The average age, height, weight, and BMI were: 24.44 ± (5.07 SD) years, 1.70 ± cm (0.06 SD), 61.65 kg ± (2.08 SD), and 21.22 (1.74 SD), respectively, trained in endurance sports, in the modalities of long-distance athletics.

Written informed consent was obtained from all participants. All research activities were carried out in accordance with the relevant guidelines and regulations and in line with the Helsinki Declaration. The study was approved by the National University of Colombia (Research Ethics Committee (Approval no: 52249)

Experimental procedure —The participants attended the Sports Science Center (Coldeportes - Bogotá, Colombia), in order to perform an initial medical assessment; personal data and background were collected, as well as training level, physical examination, height and weight measurement. Pretest evaluation, a biochemical (CK) and performance (CMJ) test was applied in the following order:

Biochemistry — Prior to the protocol session players were assessed for creatine kinase in a rested state (pre test) and then completing three CMJ assessment. Thereafter, the athletes (3 hours post) performed the same tests. The CK measurement was performed by the Reflotron® Plus equipment. (2008, Roche Diagnostics, S.L). To take the blood sample, a puncture is made in the earlobe to obtain capillary blood; later the analysis is performed by means of Reflotron test strips. The reference values for CK range from 200 to 250 U/L in men (Mougios V. 2007). Blood CK was assessed as an indirect marker of muscle damage at the same time points as neuromuscular fatigue.

Measurement of jump performance — During this study, each athlete performed three maximum effort trials of a CMJ (The mean of 3 repetitions was used as a representation of participants neuromuscular characteristics). Each participant stood still and waited for the subsequent verbal instruction of 'GO, JUMP' and then performed a preparatory downward movement to approximately 90 degrees of knee flexion. Arm movements were restricted. The leg extensor muscles were elongated (eccentric contraction), followed by maximal explosive extension of concentric contraction (opposite direction) (Gutiérrez-Dávila et al., 2014). Sixty seconds of rest was given between jumps. The variables of CMJ (flight time, time to peak force, time to peak force, peak power, contraction time, peak velocity, jump height, ratio flight time/contraction time) (Gathercole et al., 2015) were recorded and analyzed by extracting the data from use of "Passport" brand contact platform, measuring the vertical reaction force of athletes in conjunction with the software "force deck: neuromuscular performance technologies, version 105197 Build 37401".

Fatigue protocol —To test the effects of running specific fatigue on performance during one session, athletes performed a training long-distance. These protocols were designed with the participation of national coach, according to the intensity and duration that usually produced more fatigue in the athletes. The objective is to cause the maximum possible fatigue mediated by specific high intensity not by training volume. At pre-test and post-test, the athletes performed: 3 CMJ test and 6 sections of 2000 meters, with 2-minute breaks between each section (maximum possible pace and with the specific gesture of sport). The time of each stretch varies according to the conditions of each sportsman or woman (4:10 K to 4:50k). All the activities were performed at the maximum possible pace for the time of each repetition, which are above of race pace.

The experimental procedures were conducted twice, less than 5 days apart. On the first day, each participant was required to attend familiarizations with the fatigue protocol and sprints, while on the second day, the experiment was conducted. Prior to testing, participants completed a standardized warm-up procedure consisting of 10 min of jogging (8 km·h−1) and ten min of dynamic stretches for the major lower-limb muscle groups. Participants were requested to refrain from training during the 48h preceding the testing session. For hydration, water was supplied during the test. Athletes were assessed during the regular competitive season.

Statistical Analysis —The statistical analysis was conducted using the software JASP 0.16 (University of Amsterdam, Amsterdam, The Netherlands) and GraphPad Prism 9.0 for Windows. Results are obtained as mean ± standard deviation (SD), statistical significance is constituted when $p \leq 0.05$. Within Shapiro Wilk's test some variables are considered to behave non normally. Wilcoxon signed-rank test (non-parametric test) was performed to reveal differences between the parameters of neuromuscular fatigue before and after the countermovement jump test paired samples of variables (Cáceres, 1994). Spearman correlation tests were used to evaluate the relationship between CMJ jump test variables and biochemical variable CK. Cohen's d were calculated to measure the magnitude of practical effect, with the following criteria used: 0.1 as trivial, 0.2 as small, 0.5 as medium, and 0.8 as large (McGough & Faraone, 2009).

3. Results

To determine whether the different measurements of CMJ variables present significant differences in the athletes before the fatigue protocol (pre-sample) and after (post sample), the Wilcoxon signed rank test was applied. It is determined that there are statistical differences only in two specific (Figures 1 and 2, respectively) variables (Table. 1). It is highlighted within the study that neuromuscular fatigue in endurance athletes is evidenced through the increase in contraction time of eccentric phase together with concentric phase at the time of performing the CMJ test In accordance with the above, the decrease of such periods of muscle contraction within the stretch-shortening cycle (SSC), also affects the capacity of explosive performance in terms of speed since a longer eccentric duration of execution in the beginning of jump performance. Furthermore, CK concentrations were not sensitive to the intensity protocol demands in acute phase.

Table 1. **Results of Wilcoxon signed-rank test**

Variable	Pre (Mean/±SD)	Post (Mean/±SD)	*p*	*d*
Mean force	12.06±2.10	12.76±2.52	.62	.03
Time to peak force	11.02±2.33	12.30±2.90	.46	.43
Jump height	29.53±3.89	27.631±3.60	.19	.65
Flight time	0.47±0.03	0.45±0.04	.26	.58
FT: CT	2.45±0.66	2.45±0.65	.74	.59
CK	395.75±271.49	417.37±290.67	.79	.31
Peak power	61.04±9.68	56.48±9.15	**.008**	1.37
Contraction time	3.16±1.63	4.04±1.72	**.01**	.76

FT: CT = ratio (flight time/contraction time). CK: Creatine kinase. d = Cohen's d

Correlations — It was carried out the analysis of Spearman's correlations between the delta of variables on jump performance and the CK. Significant differences were found in the peak power (PP) variables ($p = 0.002$) ($r = 0.92$) and contraction time (CT) ($p = 0.001$) ($r = 0.97$). This means that correlation of PP and CT variables could have a relationship in the assessment of neuromuscular fatigue. (Figures 3 and 4, respectively). In addition, no significant relations were found between CMJ variables and the CK.

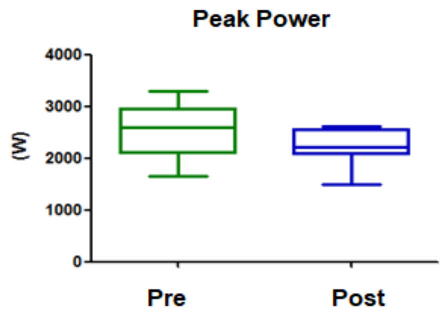

Figure 1. CMJ Variables: Peak power

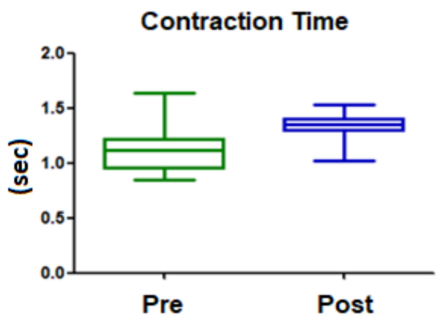

Figure 2. CMJ Variables: Contraction time

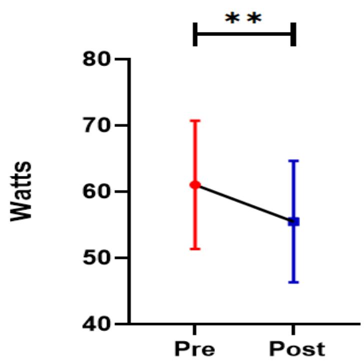

Figure 3. Correlation peak power (PP)

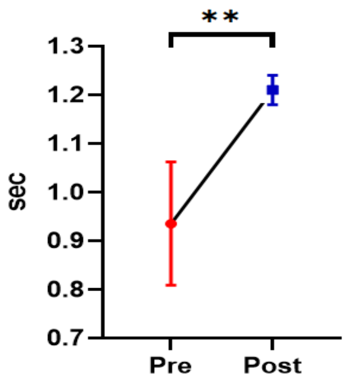

Figure 4. Correlation contraction time (CT)

4. Discussion

This work aimed to determine the variables of acute NMF and its correlation with the serum concentration of CK pre- and post-training through performance analysis CMJ. Muscle fatigue within the sports environment is a result of prolonged exercise, since due to metabolic changes in the acting fibers (Tornero-Aguilera et al., 2022b), the capacity to produce force and peak power can be reduced by altering the excitatory activity of the muscle membrane and contraction.

Moreover, the high intensity exercise will cause the depletion of muscle glycogen by modifying its metabolic process (Theofilidis et al., 2018). Otherwise, the risk of injury, the difficulty of recovery and the change of muscle activation patterns are factors of great interest to athletes as they can interfere with their performance (Fort Vanmeerhaeghe & Romero Rodriguez, 2013; St Clair Gibson et al., 2001). Several studies (D. A. Boullosa et al., 2011; Cormack, Newton, & McGuigan, 2008; Coutts et al., 2007; Gathercole et al., 2015) have investigated the importance and influence of neuromuscular function and factors involving athletes competing in races. According to the above, it is important to highlight the performance variables through CMJ test in relation to CK. This could be explained by cessation or slowing of motor units firing contributes to the loss of force and decrease in excitability to excitatory synaptic input more than the production of creatine kinase in the blood.

According to performance of the jump, the increase in duration of stretching phase (eccentric phase) and decrease in the magnitude of phase along with a lower RFD and peak power, is an indicator of neuromuscular fatigue(Alba-Jiménez et al., 2022; Maffiuletti et al., 2016) as training loads increase. This concept is related to the collected researches, being similar to the present study where the neuromuscular fatigue could be manifested analyzing the effects both in the mechanics of the eccentric and concentric phase (contraction time) of the executed CMJ. (Gathercole et al, 2015, 2015b).

In the same way, the increase of the duration of the stretching phase (longer time of muscular contraction) together with the decrease of power peak and rate force of development (D'Emanuele et al., 2021), is also related to the alteration of peak velocity concentric where the longer time used in the gesture, will produce less force during the concentric phase (Kibele, 1998). As data of interest, it is estimated that the performance in eccentric phase of CMJ decreases the impulse in the concentric acceleration-propulsion phase, due to the changes obtained in the mechanics of eccentric phase according to the diverse existing studies (Alba-Jiménez et al., 2022; Cormie et al., 2010; Wu et al., 2019)

Regarding to research on long-term endurance athletes, there are influences of neuromuscular peripheral fatigue factors on athlete performance. (Marqués-Jiménez D et al, 2022, Gathercole, 2015, Cormack, 2013, Boullosa, 2011). Furthermore, the peripheral fatigue reduces in the contractile strength of muscle fibers with changes in the mechanisms underlying the transmission of muscle action potentials and therefore, is used CMJ test to characterize fatigue in functional lower body dynamic performance following acute training or competence and are generally focused on discrete time dependent variables (Cormack, Newton, McGuigan, et al., 2008; Halson, 2014; Marqués-Jiménez et al., 2022; Theofilidis et al., 2018) derived from the ground reaction force (such as maximal or peak concentric force, power or velocity, flight time contraction time relation, peak power and other). Consequently, there are particular values within CMJ test where the study variables can register higher, lower or equal values in athletes (Cormack 2008, McLean 2010, Boullosa 2011).

In addition to tests measuring neuromuscular performance, it is common place for coach and sports scientists to evaluate CK like a one of the markers most particular in collective and individual sport modalities (Hartmann & Mester, 2000; Kindermann, 2016) to analyze a variety of markers of muscle damage (Peake et al., 2005). In our study, there were reductions and greater changes in lower body power following endurance load. The reason for this disparity could be related to the greater running loads performed (High-speed activity) during the run session.

Indeed, increases in training charges are likely to lead to greater reductions in CMJ performance and increase or not of CK levels in the first hours post exercise (Duffield et al., 2012). High intensity speed running is also thought to contribute to the major fatigue level lower body neuromuscular (McLellan et al., 2011; McLellan & Lovell, 2012; Twist et al., 2012; Wu et al., 2019) and therefore likely to generate changes in lower limbs, indicating that increasing the running loads, results in decrease in particular power.

In the same way, CK variable that showed no changes after the fatigue test, would allow correlates with mechanical variables that have shown significant changes, due to the "Post-activation Potentiation" process (D. Boullosa et al., 2018). Therefore, the chemical, mechanical and neuromuscular changes may occur generated by phosphorylation of myosin light chains of muscle tissue in an acute state like this study (Sale, 2004).

In other hand, the greater increases in blood CK observed following the athletic session can be attributed to the sports performance requirement. This substantiates the findings of others who have reported significant correlations between the number of sessions performed during competition and increases in CK (McLellan et al., 2011; Twist et al., 2012). However, eccentric muscle actions associated with the speed and foot impact of contact surface, are factors could be taken into account as a source of muscle damage (Bontemps et al., 2020).

Specifically, it is important to make it known that neuromuscular fatigue has a great relationship and influence between strength of lower limbs and CMJ performance, which is identified in the execution phases of shortening stretch cycle (eccentric - concentric) where contraction time, peak power and peak velocity are variables concerning the RFD performance (Maffiuletti et al., 2016). In particular, this explosive strength is the ability to increase force as quickly as possible, and when decrease to generate a minor propulsion and impulse acceleration in the concentric phase due to decrease of strength and tendon muscle stiffness (Toumi et al., 2006). These effects are also related to a lower peak power in the jump (D'Emanuele et al., 2021; Maffiuletti et al., 2016) and which correspond to high intensity resistance training in endurance athletes.

One of the weaknesses of this study is the number of athletes included in the present research would be considered as small. Nevertheless, understanding gained from this study can help us to design future research directions that can support to magnify improvements of our knowledge of the relationships between CMJ performance and CK levels in athletics runner.

Finally, based on the data obtained from the significant differences found in the variables of time to peak force (TTPF) and flight time (FT) in correlation with CK, these may vary depending on strength capacity of each athlete, even in the presence of elevated levels of enzymes (Lehmann et al., 1993; Magrini et al., 2017; Peake et al., 2005), which highlights the importance of neuromuscular performance and monitoring of athlete through the study of CMJ performance variables, since a particular behavior of athlete in terms of neuromuscular fatigue or potentiation can occur in acute phase according to the type of physical demand and sport modality to which belongs.

5. Practical Applications.

The practical application of the current study is that the fatigue protocol induced by running, increase the physiological strain, as well as reduce peak force performance and impair neuromuscular variables affecting the athlete's performance in acute phase. This is significant because, the monitoring taken by athletes may depend on whether the athlete is engaged in individual or team sport activity; however, the importance of individualization of load monitoring can´t be highlighted. Convenient monitoring of training load can generate important information to coaches and athletes, checking mechanical and chemical variables not only in the acute phase but 24, 48 and 72 hours after demanding exercise.

6. Conclusions

In conclusion, from the results of this study, we could identify there is a neuromuscular fatigue state in acute phase about CMJ variables, independent of relation CK production which could increase or not in a longer follow-up period. Likewise, it is highlighted a major parameter the reduction of peak power and increment of contraction time in the neuromuscular performance. Regarding this point, the CMJ is the test that is more frequently used to assess the neuromuscular status substantiating the value of use vertical jump test as a peripheral fatigue tool of interpretation. Furthermore, creatine kinase is not an only useful indicator of neuromuscular fatigue in endurance runner athletes. Finally, athletes who have competed in high intensity situations should be monitored due to possible reductions in neuromuscular performance below baseline values independent of CK, in longer assessment periods of duration.

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Conflicts of Interest: The authors declare no conflict of interest.

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