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Concurrent Fatigue and Potentiation in Endurance Athletes

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Purpose: Countermovement jump (CMJ) and maximum running speed over a distance of 20 m were evaluated for examination of the concurrent fatigue and post-activation potentiation (PAP) in endurance athletes after an incremental field running test. ***Methods:*** Twenty-two endurance athletes performed two attempts of CMJ on a force plate and maximum running speed test before and following the Université de Montréal Track Test (UMTT). ***Results:*** The results showed an improvement in CMJ height (3.6%) after UMTT that correlated with the increment in peak power (3.4%), with a concurrent peak force loss (–10.8%) that correlated with peak power enhancement. The athletes maintained their 20 m sprint performance after exhaustion. Cluster analysis reinforced the association between CMJ and peak power increments in responders with a reported correlation between peak power and sprint performance increments ($r = .623$; $P = .041$); nonresponders showed an impairment of peak force, vertical stiffness, and a higher vertical displacement of the center of mass during the countermovement that correlated with lactate concentration ($r = -0.717$; $P = .02$). ***Conclusions:*** It can be suggested that PAP could counteract the peak force loss after exhaustion, allowing the enhancement of CMJ performance and the maintenance of sprint ability in endurance athletes after the UMTT. From these results, the evaluation of CMJ after incremental running tests for the assessment of muscular adaptations in endurance athletes can be recommended.

Keywords: countermovement jump, sprint, maximum aerobic speed, exhaustion, field

During recent years, various studies investigated the influence of neuromuscular factors on distance running, in particular, the relationship between muscle power factors and endurance running.[1,2] Furthermore, different modalities of strength training with emphasis on power characteristics have been demonstrated to promote a higher running economy[3–5] and a higher endurance performance.[1,6] This

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suggests that metabolic adaptations could also be accompanied by neuromuscular adaptations when a runner improves his running test results after a training period. Consequently, the evaluation of power concurrently with running performance should be considered for the monitoring of endurance athletes.

Postactivation potentiation (PAP) refers to the phenomena by which muscular performance characteristics are acutely enhanced as a result of their contractile history.[7] Some authors[8] have reported an acute enhancement of power and jump capacities after an incremental protocol until exhaustion in a cohort of elite distance runners. This enhancement is contrary to the expected effect of fatigue on power characteristics following running until exhaustion.[9,10] Other authors[11] have shown the influence of two exhausting, running protocols on the PAP profile while jumping and indicated that this PAP has not been reported in a group of physically active nonrunners. Therefore, it may be suggested that the PAP response, after running exercises, is specific for endurance-trained subjects with different responses detected depending upon the mode of the running protocol. Furthermore, the paradox of jump enhancement after exhaustion is interesting and may indicate the coexistence of PAP and fatigue[12] where the PAP-fatigue relationship affects subsequent voluntary activity.[7]

Potentiation is expected to occur after evoked contractions and after near-maximum or maximum voluntary conditioning exercises in power-trained athletes when performing explosive tasks.[7] Similarly, twitch-potentiation has also been observed in endurance-trained athletes in evoked contractions after maximal voluntary contractions,[13] moderate-intensity isometric voluntary contractions,[14] and continuous[15] and intermittent running bouts.[16] Moreover, PAP has also been reported in endurance trained athletes in jump performance after intermittent,[8] continuous running exercises,[8,17] and incremental protocols.[8,11] From these previous studies, it can be suggested that the nature of the conditioning activity for PAP may be dependent upon the chronic training adaptations experienced by subjects. While athletes experienced in endurance training would demonstrate PAP after conditioning activities that stimulate slow-twitch fibers, those athletes experienced in power training would experience PAP after conditioning activities that stimulate primarily on fast-twitch fibers. In this regard, some authors[8] reported correlations among jump enhancement, training volume, and maximum aerobic speed (MAS), suggesting a relationship between muscular chronic adaptations of elite endurance runners and the acute responses under fatigue. In contrast, others[11] failed to observe similar correlations between variables. Subsequently, it would be important to examine further the potential relationships among training, running, and mechanisms for PAP.

A countermovement jump (CMJ) is an easy-to-perform test, which is a neuromuscular fatigue assessment of athletes.[18] Previously, it was suggested that an enhancement of elastic energy transfer occurs in a fatigued condition in CMJ with both impairment[18] or enhancement[8] of performance. Previous studies of distance runners[8,11] evaluated PAP and jump capacity with the flight-time method. However, the characteristics of the force-time curve during the push-off phase remain still unknown when looking for mechanical differences when PAP occurs. Another easy field test for neuromuscular fatigue evaluation is the maximal 20 m sprint test.[9] Interestingly, the velocity loss in this test after a 5 km trial has been related to the nonfatigued performance.[10] Subsequently, mechanical parameters during a CMJ and sprint performance could be considered valid for the evaluation of concurrent postexercise PAP and fatigue.

Thus, the aim of this work was to study mechanical differences when endurance athletes perform a CMJ on a force plate before and after the Université de Montréal Track Test (UMTT).[19] This field running test was selected because it is appropriate for both endurance running evaluation[20] and fatiguing exercise.[11] In addition, the maximal sprint velocity over 20 m sprint was evaluated for comparison between both conditions. The hypothesis was that the PAP and fatigue induced by the UMTT could be reflected in the changes in mechanical parameters during the CMJ and in maximal sprint velocity over 20 m.

Methods

Participants

Twenty-two experienced endurance athletes (8 female and 8 male endurance runners, and 6 male triathletes) of heterogeneous level (from regional to elite) and training background volunteered for participation in this study. The sample was evaluated throughout the months of July to September, immediately following the end of the runner's competitive season. However, the triathletes were still competing. Their characteristics are shown in Table 1. The local ethics committee approved this study design for experimentation with human participants. All participants were informed of all procedures and provided informed written consent.

Table 1 Characteristics of participants, mean (SD)

***N* = 22**	**Mean (SD)**	**Range**
Male Runners (*n* = 8)		
Age (y)	24 (4.3)	18–28
Height (cm)	179.9 (8.3)	171–196
Body mass (kg)	68.4 (7.5)	54.2–75
% Body fat (% BW)	7.8 (0.7)	6.6–8.9
Maximum aerobic speed (km·h^{-1})	20.1 (0.6)	19–21
Female Runners (*n* = 8)		
Age (y)	22.5 (5.5)	18–31
Height (cm)	165.5 (5.5)	158–174
Body mass (kg)	53.9 (3.8)	47.6–59
% Body fat (% BW)	13.8 (2.6)	10.1–18.4
Maximum aerobic speed (km·h^{-1})	18.1 (1)	16–19
Male Triathletes (*n* = 6)		
Age (y)	28.5 (6.2)	18–35
Height (cm)	175.3 (4.6)	171–181
Body mass (kg)	67.2 (4.1)	63.2–73.5
% Body fat (% BW)	7.8 (0.5)	7.3–8.5
Maximum aerobic speed (km·h^{-1})	18.3 (0.5)	18–19

Note. BW: body weight.

Procedures

Participants were evaluated individually on two occasions. A preliminary session in the laboratory was employed for both anthropometric evaluation and familiarization of participants with CMJ performance. This preliminary session was conducted between 48 h and 1 wk before the field evaluation session with participants advised to avoid strenuous exercise 72 h before. The second session was conducted on a 400 m outdoor track with climatic conditions as follows: temperature of 21–28°C, relative air humidity of 70–80%, and barometric pressure of 735–765 mmHg.

Power Performance in Nonfatigued Condition

Participants warmed up by running on the grass for 10 min at an intensity of 60% of their estimated HR_{max} with a HR monitor (625x, Polar Electro, Finland). As part of the warm-up, the athletes practiced two to three CMJ attempts with arms akimbo immediately after the running exercise.

Recording of jump performance in the nonfatigued condition was conducted 2–3 min after the warm-up and consisted of two maximal CMJ attempts, separated by at least 15 s. Participants were encouraged to jump as high as possible. The depth of the countermovement was freely chosen by participants. These jumps were performed on a force plate (Quattro jump, Kistler, Switzerland) with a sampling rate of 500 Hz, where vertical forces were recorded. The highest jump was selected for further analysis. Jump height (CMJ) was calculated from the difference between maximum height of the center of mass (apex) and the last contact of the toe on the ground during the take-off. Peak force was considered relative to body weight (BW). Mean and peak power during the push-off phase were also obtained. Additional parameters for further analysis were the vertical path of center of mass and normalized vertical stiffness ($N \cdot m^{-1} \cdot kg^{-1}$).[21]

Immediately after jump evaluation, participants performed two attempts, separated by 2 min of recovery, of a maximal running velocity test over 20 m. Distance for acceleration was freely chosen by participants (ie, 25–40 m) and performed in progression for achieving a true maximum sprint speed over a 20 m section recorded with a photocell portable system (Chronomaster, Spain) having an accuracy of +0.001 s. Maximum running speed was calculated from the recorded lap time.

Endurance Running Evaluation

The cadence of the UMTT was similar to the original (1 $km \cdot h^{-1}$ every 2 min)[19] but the velocity was imposed by a cyclist with a velocimeter that was previously calibrated (SC6501, Shimano, Taiwan). The last completed 2 min stage was considered as the maximum aerobic speed (MAS). The final time of the test was also recorded (T_{UMTT}). This test is highly reproducible in athletic populations with the maximum aerobic speed demonstrating significant and high correlations with running performance.[20] At the end of the running test, exhaustion was confirmed by an RPE > 19 (6–20 Borg's scale) and attainment of estimated HR_{max}. Immediately after the UMTT, blood samples were taken from the fingertip for lactate measurement with a portable lactate analyzer (Lactate Scout, Senslab, Germany) for characterization of effort and as an additional exhaustion criterion (> 8 $mmol \cdot L^{-1}$).

Power Performance in Fatigued Condition

At the end of the UMTT, participants walked to the starting point where the force platform and the photocells were placed. At the second minute of recovery they performed two attempts of the CMJ. This recovery time was necessary because the final location of the athlete at the end of the UMTT may be uncertain, and also because it has been demonstrated to be appropriate for our purposes.[11] After CMJ evaluation, participants performed two attempts of the maximal 20 m running test (third and fifth minute of recovery) as previously described. Percentage of changes of power performance parameters were calculated (Δ) for further analysis.

Statistical Analysis

To confirm a normal distribution for variables, a Kolmogorov-Smirnov test was performed. Statistical descriptives are shown as means (SD). To assess within-trial reliability of jump and sprint tests, intraclass correlation coefficients (ICCs) were calculated. Paired *t* tests were performed to identify pre- to post-trial UMTT changes. On the basis of the distribution of the change in CMJ (ΔCMJ), participants were also categorized as *responders* and *nonresponders* (ie, cluster analysis) for a better analysis of the variance as the distributions of selected parameters were mainly leptokurtic. The cluster analysis was automatically performed with the SPSS software (v.16.0.2, Chicago, IL). Square Euclidian distance was chosen as distance measurement method. A two-way ANOVA (moment × cluster) with repeated measurements was used to detect significant differences between conditions and clusters with post hoc analyses (Bonferroni) conducted if necessary. The factors gender and sport modality were not be considered for analysis because of their low number and homogeneity. Partial correlation coefficients (adjustment for gender) were employed for analysis of the relationships between selected parameters. Cohen's *D* was also performed as a complementary effect size calculation ($D = 0.2$, small; $D = 0.5$, medium; $D = 0.8$, large).

Results

Running performance for the UMTT resulted in a T_{UMTT} value of 1476 ± 145 s with a MAS of 18.9 ± 1.2 km·h^{-1}. The HR_{max} recorded at the end of the running protocol was 189 ± 11 bpm with a lactate concentration of 9.6 ± 1.9 mmol·L^{-1}.

Reliability for CMJ was high in the nonfatigued (ICC = 0.889) and fatigued (ICC = 0.939) condition. The UMTT led to a significant increase in CMJ (ΔCMJ = 3.6 ± 6.1%; $P = .008$) and peak power (Δpeak power = 3.4 ± 6.1%; $P = .035$), and a significant decrease in peak force (Δpeak force = –10.8 ± 20.4%; $P = .027$). There were no other significant changes in the remaining parameters although there was a tendency for a decrease in the vertical path of the center of mass ($P = .076$) and vertical stiffness ($P = .074$) (see Table 2).

Significant correlations were identified between ΔCMJ and Δpeak power ($r = .658$; $P = .001$) and Δmean power ($r = .643$; $P = .002$). Δmean power was correlated with Δpeak force ($r = .857$; $P = .000$) and Δpeak power ($r = .722$; $P = .000$) while Δpeak force was correlated with Δpeak power ($r = .480$; $P = .028$) (see Figure 1). No significant correlations were found between jump or sprint and endurance performance parameters.

Table 2 Mean (SD) values of force-time parameters of the best CMJ before (Pre; nonfatigued condition) and after (Post; fatigued condition) the Université de Montréal Track Test. Percentage of changes (Δ%) are also reported.

Variables	Pre	Post	Δ%
CMJ (cm)	29.5 (5.5)	30.6 (5.4)	3.6 (6.1)†
Mean power ($W \cdot kg^{-1}$)	24.9 (5.5)	24.8 (5.2)	–0.1 (8)
Peak power ($W \cdot kg^{-1}$)	43.3 (10.2)	44.8 (9.7)	3.4 (6.1)*
Vertical displacement of center of mass (cm)	27.4 (6.3)	28.9 (6.6)	4.3 (12.5)
Maximum force (BW)	2.25 (0.26)	2.14 (0.21)	–10.8 (20.4)*
Vertical stiffness ($N \cdot m^{-1} \cdot kg^{-1}$)	99.6 (39.1)	92 (32.2)	–9.4 (19.9)

Note. CMJ: countermovement jump; BW: body weight. † $P < .01$; * $P < .05$.

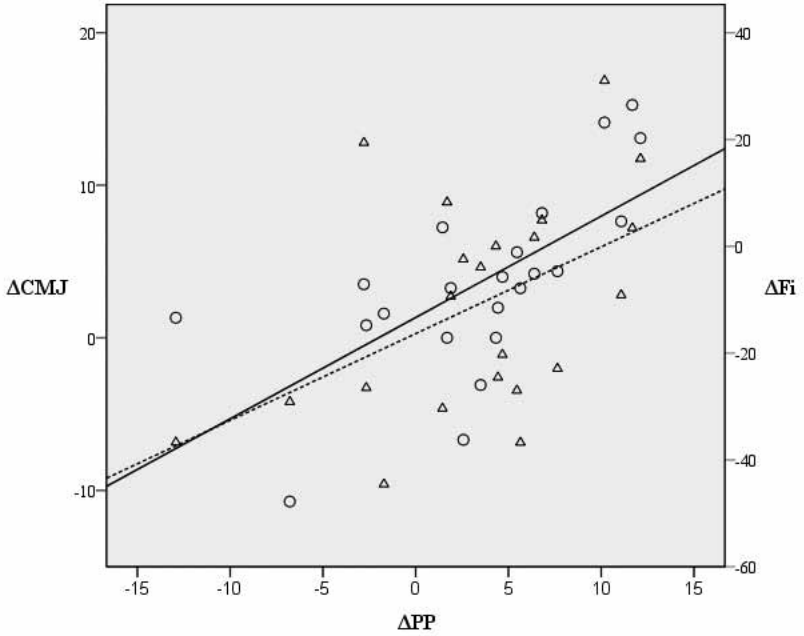

Figure 1 — Relationship between the pre–post changes (%) for peak power (ΔPP) with countermovement jump (circles, continuous line) (ΔCMJ; $R^2 = .43$) and maximum force (triangles; dashed line) (ΔFi; $R^2 = .24$).

Reliability for sprint performance was high in the nonfatigued (ICC = 0.96) and fatigued (ICC = 0.959) condition. There was no significant difference ($P = .993$) between sprint performance in the nonfatigued condition (29.3 ± 2.5 $km \cdot h^{-1}$) and after the UMTT (29.3 ± 2.5 $km \cdot h^{-1}$).

Cluster Analysis

Analysis of variance of clusters (see Table 3) revealed significant differences between conditions in some mechanical parameters for *responders (5 male runners, 5 female runners, and 2 triathletes)*: ΔCMJ (+4.9%; *P* = .01), Δpeak power (+5.8%; *P* = .038); and for *nonresponders*: Δvertical path of the center of mass (+9.7%; *P* = .043), peak force (–29.9%; *P* = .000), and a tendency in vertical stiffness (–16.6%; *P* = .052; Cohen's *D* = 0.48). A significant moment × cluster interaction was identified for mean power (*P* = .000) and peak force (*P* = .000) with *responders* demonstrating greater values compared with *nonresponders*. Significant correlations between ΔCMJ and Δpeak power (*r* = .752; *P* = .005), ΔCMJ and Δmean power (*r* = .840; *P* = .001) and between Δpeak power and Δsprint performance (*r* = .623; *P* = .041) were detected for *responders*. For *nonresponders*, only a correlation between lactate concentration and Δvertical path of the center of mass (*r* = –0.717; *P* = .02) was exhibited. No correlations were found between jump and endurance running performance parameters for any clusters.

Discussion

The first finding of this study is the confirmation of the PAP experienced by a group of endurance athletes, from different genders and training backgrounds, after an incremental running test, which is similar to previous studies with distance runners.[8,11] This PAP was confirmed with the utilization of a force plate for jump evaluation, whereas prior studies have utilized a flight-time method that overestimates the true flight height[22] that could potentially bias results. In this regard, it is interesting to note the differences in ΔCMJ among studies for well-trained male runners with one study[8] reporting an 8.9% change, and another study[11] reporting a 12.7% change. However, the current study found a smaller change of 4.9%. From these observations, we suggest considering these methodological issues in future studies, specifically with regard to athlete´s posture during CMJ landing on contact mats.[23] Further studies are needed for the assessment of the possible influence of the method employed in PAP magnitude.

Regarding mechanical parameters, the significant correlations found between ΔCMJ with Δpeak power and Δmean power; Δmean power with Δpeak force and Δpeak power; and Δpeak force with Δpeak power, demonstrated that those athletes with the smaller loss of peak force enhanced their CMJ performance via peak power increments. These relationships between selected parameters could explain that PAP as CMJ performance is highly related to peak power.[24] Further, as the mean power was related to the overall push-off phase (eccentric plus concentric movement) and its change (Δmean power) significantly correlated with Δpeak force, it may be suggested that participants having a smaller loss of peak force could maintain the overall mean power and improve the subsequent peak power enhancement as represented on Figure 1. The reported higher peak concentric and eccentric forces, and greater peak power values for a higher CMJ support this rationale.[25]

The most affected parameter by fatigue was peak force (–10.8%), suggesting a negative influence of fatigue for the development of maximum forces. Interestingly, vertical stiffness was affected by fatigue, but this change did not achieve statistical significance (–9.4%; *P* = .109; Cohen's *D* = 0.21). Previously, others[26] described

Table 3 **Mean (SD) values of force-time parameters of the best CMJ before (Pre; nonfatigued condition) and after (Post; fatigued condition) the Université de Montréal Track Test for every cluster considered (Responders; *n* = 12; Nonresponders; *n* = 10). The *p* value of the moment × cluster interaction for every parameter is also reported.**

	Responders		Nonresponders		ANOVA 2 × 2
Variables	**Pre**	**Post**	**Pre**	**Post**	***P* =**
CMJ (cm)	29.6 (4.9)	31.2 (4.5)†	29.3 (6.3)	29.9 (6.5)	0.241
Mean power ($W \cdot kg^{-1}$)	24.1 (4.7)	25.3 (4.6)	25.8 (6.4)	24.2 (5.9)	0.000
Peak power ($W \cdot kg^{-1}$)	41.9 (8.6)	44.4 (9.1)†	45 (12.1)	45.1 (10.9)	0.053
Vertical displacement of center of mass (cm)	27.6 (6.8)	27.7 (7.4)	27.3 (6.1)	30.2 (5.7)*	0.064
Maximum force (BW)	2.2 (0.3)	2.3 (0.2)	2.3 (0.2)	2.0 (0.1)†	0.000
Vertical stiffness ($N \cdot m^{-1} \cdot kg^{-1}$)	102.5 (44.2)	100.3 (36.4)	96 (34)	81.9 (24.4)*	0.144

Note. CMJ: countermovement jump; BW: body weight. † $P < .01$; * $P < .05$.

the effect of fatigue on the biceps femoris, rectus femoris, gastrocnemius and vastus lateralis in elite endurance runners during the last stages of an incremental running protocol. In this regard, it is tempting to establish a relationship between the fatigue of these muscle groups and the smaller capacity for the development of force in the deeper positions of the center of mass during the countermovement. Nevertheless, the highest capacity for developing PAP in the slighter fatigued athletes is in agreement with the previously suggested relationship between the lower level of fatigue and higher potentiation whereby both phenomena coexist and could be simultaneously modified with training intervention.[12]

Another possible mechanism for this PAP may include an enhancement of elastic energy transfer[8,18] in CMJ after fatiguing tasks. These prior studies suggested an enhancement of elastic energy in the fatigued state via the difference between CMJ and squat jump performances[18] and the higher mechanical power with a reduction in EMGrms of the knee extensor muscles during half squats.[8] Others[24] suggested that peak power may not be a good measure of the working capacity of any muscle and may be an indication of how effectively energy is transferred between body segments. From these observations, we may suggest that PAP itself could explain these mechanical changes counteracting the force loss in the eccentric action and increasing power production in the concentric action.

The maintenance of maximum sprint performance in the fatigued condition is surprising given the previous reported impairment of sprint ability after a 10 km trial[9] and after a 5 km trial[10] in endurance runners. Previously, some authors[9] did not find any difference between low- and high-caliber athletes in sprint performance after a 10 km. More recently, others[10] found a correlation between sprint ability before a 5 km trial and the velocity loss after this running trial. As we did not find any correlation between similar parameters in the current study, it may be speculated that running test mode (ie, incremental vs distance trial) may be important for the consideration of fatigue origin and its influence on sprint performance under fatigue. As we did not find a deterioration of this ability after conduction of the ramp test, it may be suggested—for a practical point of view—the evaluation of maximum sprint ability after incremental tests allowing coaches some economy in time evaluation. While our testing schedule was designed for a proper examination of the PAP on two different exercises in a field setting, further studies are needed for a more precise evaluation of the sprint ability after incremental tests compared with other testing modes,[9,10] specifically with regard to the different origins of fatigue among conditions, while this capacity is very important to the final rushes of the races.

For a better understanding of the mechanical differences, we decided to incorporate cluster analysis, as members of the same cluster are likely to have more similar responses. Two clusters of endurance athletes were obtained from the different magnitude of the ΔCMJ. These clusters were categorized as *responders* ($n = 12$; ΔCMJ = 5 ± 6.9%) and *nonresponders* ($n = 10$; ΔCMJ = 1.9 ± 4.9%). From this analysis, *responders* confirmed an improvement of CMJ in fatigued condition via enhancement of peak power. Interestingly, this group demonstrated a correlation between Δpeak power and Δsprint performance, suggesting the simultaneous influence of PAP during these different exercises. *Nonresponders* demonstrated a significant impairment of peak force and vertical stiffness with a higher value for vertical displacement, reinforcing the negative influence of local fatigue on the capability of athletes to demonstrate PAP during power performance. Moreover, a correlation was found between lactate concentration and the changes in vertical displacement during jumping. The sign of this correlation is opposite to the expected influence of lactate on fatigue as it means that the higher the lactate concentration, the lower the depth of the countermovement for this cluster. Therefore, while it may be suggested that there is a complex response of the neuromuscular system under fatigue from all these results, the ANOVA analysis (moment × cluster) revealed some interactions for maximum force and mean power with both tendencies detected for vertical displacement and peak power. Subsequently, it was confirmed there is a differentiated response of every cluster after the fatiguing, running exercise with emphasis on the role of the force preservation for the subsequent improvement in jump performance.

The absence of correlations between endurance running and jump or sprint performance parameters is contrary to a previous study[8] but in agreement with another one.[11] These authors[8] found some correlations of ΔCMJ with training volume, MAS, CMJ, and 20 m sprint performance. While we did not find any correlation regarding these parameters, it is interesting to note the superior ΔCMJ value of the higher vs. lower quintile of T_{UMTT} (8% vs 1.4%) s in the current study independently of the level and the training background of the athletes. From this observation, it may be suggested that the number of stage increments during the incremental test could favor athletes who run a greater proportion of their time during the UMTT at submaximal intensities,[27] experiencing a greater musculature stimulation[14] for the subsequent PAP in a dose-response manner. Previous evidence of a greater ΔCMJ after a tempo running (40 min at 80% of maximum aerobic speed; ΔCMJ = 14.5%) compared with an incremental protocol (ΔCMJ = 8.9%);[8] and the UMTT (ΔCMJ = 12.7%) compared with the time limit at maximum aerobic speed (ΔCMJ = 3.5%),[11] support this rationale. Further, some of the advanced athletes in the current study were included in the *nonresponders* cluster despite having a higher MAS in respect to their counterparts. Therefore, this would confirm that the tolerance to muscular fatigue may be the more important factor for the achievement of a higher jump height after exhaustion independently of the MAS recorded.

Practical Applications

We suggest coaches evaluate the CMJ performance after incremental tests as an easy-to-perform test reflecting muscular fatigue tolerance and PAP in endurance running. Given the simultaneous influence of training in muscular fatigue and potentiation,[12] it may be considered the evaluation of vertical jump performance after ramp tests for the assessment of muscular adaptations in endurance athletes. Moreover, it may be suggested that the appropriateness of the evaluation of the maximum sprint ability after incremental tests as this capacity has demonstrated no deterioration after exhaustion when compared with nonfatigued conditions. For example, if an athlete experienced PAP in a CMJ after an incremental test and some weeks later the same athlete did not experience PAP with no changes in his MAS and VO_2max, this could be interpreted as an impairment with his muscular capabilities with no changes in his metabolic adaptations.

Although a mechanical explanation for this PAP was demonstrated, it should be noted that neither the molecular basis nor the neuromuscular parameters were explored in this study. In this regard, some authors[28] have shown the different interaction between fatigue and potentiation at different muscle lengths, suggesting a link with our study in which a maximum force preservation was found with a subsequent peak power enhancement, where the former is typically at longer and the latter at shorter muscle lengths. Consequently, further studies may need to address these aspects for a better understanding of this phenomenon.

Another practical application could be to perform plyometrics immediately after non- exhaustive running exercises, allowing the benefit of the PAP as in other sport modalities (ie, complex training).[29] Nevertheless, this question requires further experimental research for the assessment of the higher effectiveness of this training method if compared with other forms of concurrent strength and endurance training.

Conclusions

In summary, PAP was demonstrated after an incremental exhaustive protocol in endurance athletes with higher CMJ performance in those athletes with concurrent higher peak power increments and maximum force preservation. In addition, maintenance of maximum running velocity after exhaustion may be related to PAP response, and athletes who run further during a UMTT probably stimulates musculature more intensely at submaximal intensities resulting in a greater PAP. Maximum force preservation in a CMJ after a ramp test may be the more important factor for PAP in the evaluation of muscular adaptations of endurance athletes.

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