Impact of an incremental running test on jumping kinematics in endurance runners: can jumping kinematic explain the post-activation potentiation phenomenon?

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Original Investigation

Abstract

This study aimed to determine whether kinematic data during countermovement jump (CMJ) might explain post-activation potentiation (PAP) phenomenon after an exhausting running test. Thirty-three trained endurance runners performed the Léger Test; an incremental test which consists of continuous running between two lines 20 m apart. CMJ performance was determined before (pre-test) and immediately after the protocol (post-test). Sagittal plane, video of CMJs was recorded and kinematic data were obtained throughout 2-Dimensional analysis. In addition to the duration of eccentric and concentric phases of CMJ, hip, knee and ankle angles were measured at four key points during CMJ: the lowest position of the squat, take- off, landing, and at the lowest position after landing. Additionally, heart rate was monitored, and rate of perceived exertion was recorded at post-test. Analysis of variance revealed a significant improvement in CMJ ($p = 0.002$) at post-test. Cluster analysis grouped according to whether PAP was experienced (responders group: RG, n = 25) or not (non-responders group: NRG, n = 8) relative to CMJ change from rest to post-test. RG significantly improved ($p < 0.001$) the performance in CMJ, whereas NRG remained unchanged. Kinematic data did not show significant differences between RG and NRG. Thus, the data suggest that jumping kinematic does not provide the necessary information to explain PAP phenomenon after intensive running exercises in endurance athletes.

Keywords

Countermovement jump; graded exercise test; long-distance runners; neuromuscular response; two dimensional analysis.

Introduction

The evaluation of neuromuscular parameters has become an important consideration for endurance athletes and coaches and, in order to monitor neuromuscular adaptations, athletes periodically perform different tests. As indicated by Vuorimaa, Häkkinen, Vähäsöyrinki, and Rusko (1996), vertical jumping height is of interest because it is considered to indirectly reflect the capability of the leg extensor muscles to generate mechanical power. Specifically, countermovement jump (CMJ) is an easy-to-perform, neuromuscular fatigue test for assessing athletes (Bosco et al., 1986), widely used for research and for monitoring training adaptations (García-Pinillos, Soto-Hermoso, & Latorre-Román, 2015; Gorostiaga et al., 2010; Latorre-Román, García-Pinillos, Martínez-López, & Soto-Hermoso, 2014; Vuorimaa, Vasankari, & Rusko, 2000; Vuorimaa, Virlander, Kurkilahti, Vasankari, & Häkkinen, 2006). Some previous studies have investigated the kinematics of jumping, determining the influence of the knee flexion angle—during the descent phase prior to take-off and after landing—on the outcome of the CMJ (Domire & Challis, 2007; Salles, Baltzopoulos, & Rittweger, 2011) and for the injury risk (Richards, Ajemian, Wiley, & Zernicke, 1996; Ryan, Harrison, & Hayes, 2006).

The effect of fatigue induced by running exercises on jumping ability is presently not well understood. Whilst some authors have reported an acute enhancement of jump capacities (Boullosa, Tuimil, Alegre, Iglesias, & Lusquiños, 2011; García-Pinillos et al., 2015; Latorre-Román et al., 2014; Vuorimaa et al., 2006) after running protocols in runners, other authors (Boullosa & Tuimil, 2009) did not find post-activation potentiation (PAP) effects in non-runners after similar stimulus. It is well known that the contractile history of a muscle has two opposing effects on muscular force output: PAP and fatigue. The term PAP refers to the phenomenon that significantly enhances muscular twitch force after vol- untary contractile activity (Mettler & Griffin, 2012). The majority of previous studies have induced PAP through the use of maximal voluntary contractions (Mettler & Griffin, 2012), but also sub-maximum and longer or prolonged exercises can cause PAP for subsequent activities (Boullosa et al., 2011; García-Pinillos et al., 2015; Latorre-Román et al., 2014; Vuorimaa et al., 2006). There is no available consensus yet, neither about the optimal acute conditioning mode protocol, nor about influence factors in that relationship such as the types of contraction involved, the muscle groups tested, the exercise duration and intensity, or the length of recovery period (Wilson et al., 2013).

Likewise, the mechanism responsible for muscle potentiation has not been fully elucidated (Wilson et al., 2013). As proposed by Tillin and Bishop (2009), PAP could be explained by two mechanisms: an increase in the recruitment of higher order motor units, and the phosphorylation of myosin-regulatory light chains. However, according to Reardon et al. (2014), acute changes in muscle architecture may also contribute to the PAP response. A study of the changes in the biomechanics of CMJ resulting from PAP phenomenon might provide information on the mechanism responsible for muscle potentiation after exhausting running exercises.

Presently, there is a lack of information about the mechanism responsible for the PAP phenomenon after running exercises in endurance runners. The main purpose of this study was therefore to determine whether kinematic data during CMJ might explain PAP phenomenon after an exhausting running test, the Léger test (Léger, Mercier, Gadoury, & Lambert, 1988). The authors hypothesise that improvements observed in CMJ performance despite high exhaustion levels, might be reflected in the manner by which athletes jump (jumping kinematic).

Methods

Participants

Thirty-three recreationally trained endurance runners, 20 men (age = 32.1 ± 10.4 years, body mass index (BMI) = 21.6 ± 2.4 kg/m2 and maximal oxygen consumption (VO2max) = 57.0 ± 3.1 ml/kg/min) and 13 women (age = 28.5 ± 6.9 years, BMI = 20.0 ± 1.5 kg/ m2 and VO2max = 50.0 ± 4.4 ml/kg/min), voluntarily participated in this study. The participants came from different athletic clubs in Andalusia (Spain), and the assessment protocol was performed in-season. Further information of participants is shown in Table 1. Inclusion criteria were: (a) the participants were experienced athletes, with a minimum experience of five years on the training and competition; (b) the participants trained regularly and they had no history of injury in the previous three months that would limit training. No alcohol intake was allowed the day before testing, strenuous physical exercise was not allowed for 72 h, and food intake was not allowed for the two hours immediately preceding the test. After receiving detailed information on the objectives and procedure of the study, each participant signed an informed consent for participation, which complied with the ethical standards of the World Medical Association Declaration of Helsinki (2013). The study was approved by the Ethics Committee of the University of Jaen (Spain).

[Table 1 near here]

Procedures

Even though an original assessment protocol was used in the current study, the tests performed have been included in previous works (Boullosa & Tuimil, 2009; Boullosa et al., 2011; García-Pinillos et al., 2015). Participants were tested individually on an indoor court, on one specific day, and the tests were performed in the same order. Testing was integrated into weekly training schedules, although the participants were advised to avoid strenuous exercise 72 h before. Participation involved the execution of the Léger Test (Léger et al., 1988) and the performance in CMJ was determined before and immediately after the test. This allows a comparison to be done between unfatigued condition (pre-test) and fatigued condition (post-test).

At the beginning of the testing day, a body composition analysis through InBody R20 (Biospace Co., Ltd., Seoul, Korea) was carried out. This device let us measure the body mass (kg) and percentage body fat (%). Height (m) was measured following standard procedure with a stadiometer (Seca 222, Hamburg, Germany), and body mass index (BMI in kg/m2) was calculated. Next, the participants performed a standardised warm-up, which consisted of five minutes of low-intensity running and five minutes of general exercises (high skipping, leg flexions, lateral running, front and behind arm rotations, and sprints). Then, five 13-mm-diameter retroreflective markers (fifth metatarsal, lateral malleolus, lateral epicondyle of the femur, greater trochanter, and acromion) were placed on the right side of the body (Figure 1). These landmarks defined the positions of upper body (head, arms and trunk being taken together), upper legs, lower legs and feet. After markers' placement, five minutes after warm-up was finished, the participants performed the pre-test (CMJ). Then, they completed the Léger Test and immediately after, they performed the post-test (CMJ).

[Figure 1 near here]

Materials and instruments

The Léger Test (Léger et al., 1988) consists of running back and forth between two lines 20 m apart with running speed determined by audio signals from a pre-recorded music compact disc. The running speed increases at the end of each one-minute stage. The test ends when the participants twice fail to reach the lines at the time indicated by the audio signals, demonstrating an inability to keep the required pace. It has been studied extensively in various studies with endurance runners showing a good correlation with other performance parameters (Billat & Koralsztein, 1996). The VO2max can be estimated (Léger et al., 1988) through the speed that the participants reached in the last sprint through the following equation:

$$VO2(ml/kg/min) = 5.857 \times velocity(km/h) - 19.458$$

Heart rate (HR) was monitored during the test's execution using a Garmin Forerunner monitor 405 (Kansas, USA), through which we obtain the peak HR (HRpeak), the average value (HRmean), and the HR at 1 min of recovery (HRrec). In addition, rating of perceived exertion (RPE) (Borg, 1982) was scaled by participants before and after the test to register the subjective intensity of exertion.

A CMJ test was performed to assess vertical jump ability. In each measurement (pre-test and post-test), the participants performed 3 trials, separated by 15 s of recovery. From a standing position (shod, in a balanced position with feet width similar to hip width), the participants were to dip and immediately jump for maximum height; arm swing was not allowed. The participants were required to flex their knees to an angle of approximately 90°. Trials in which athletes did not flex their knees to 90 ± 10° angles were excluded from statistical analysis. These angles were not accurately controlled by the use of any device so, to make sure the execution of the CMJ was correct, some trials of familiarisation were allowed and feedback was given to the athletes during this familiarisation session. Moreover, the participants are experienced athletes who perform CMJ in their daily training sessions. The CMJ was recorded using the FreePower Jump Sensorize device (FreePower, Sensorize, Rome, Italy), which was previously validated (Picerno, Camomilla, & Capranica, 2011). Sagittal plane video (240 Hz) of each vertical jump was recorded using a high-speed camcorder (Casio Exilim EXF1, Shibuyaku, Tokyo 151-8543, Japan). Videos were taken from a lateral view (Petushek et al., 2012), with the camera perpendicularly placed two metres from the runner. Video data were analysed using a two-dimensional video editor (VideoSpeed vs1.38, ErgoSport, Granada, Spain). The valid trial with the greatest jump height was selected for the subsequent analysis.

The dependent variables selected for the jumping kinematic were the relative angle of

the hip, knee and ankle (θhip, θknee and θankle, respectively) at four key points: (1) the lowest position of the squat (the deepest knee flexion); (2) at take-off (the last frame with ground contact); (3) at landing (initial contact after flight time); and (4) at the lowest position after landing (the deepest knee flexion), as well as the duration (in seconds) of the eccentric and concentric phases (tEcc and tConc) of the jump—data given by the accelerometer used—(Figure 2). The variables were selected according to previous works (Domire & Challis, 2007; McNeal, Sands, & Stone, 2010; Richards et al., 1996; Ryan et al., 2006; Salles et al., 2011). To make citing all these variables easier, a subscript number representing the CMJ moment was included (i.e. the hip angle at the lowest position of the squat is named θhip1). For each variable controlled in this study, the post-pre comparison was calculated and is shown as Δ (i.e. Δβhip1).

[Figure 2 near here]

Statistical analysis

Descriptive statistics are represented as mean (SD). Tests of normal distribution and homogeneity (Kolmogorov–Smirnov and Levene's) were conducted on all data before analysis. Pre- and post-test changes (Δ) were calculated for each variable. A cluster k-means was performed by grouping according to whether PAP occurred (RG: responders group) or not (NRG: non-responders group) in relation to ΔCMJ. Independent student's t-test was used to compare demographic and body composition variables between groups, whilst analysis of variance (ANOVA) was performed between groups. Within-group differences between jumping technique at pre- and post-test were calculated using paired t-test (for RG), and Wilcoxon test (for NRG). Intra- and inter-observer reliabilities were calculated using intraclass correlation coefficients (ICCs) and confidence interval (CI). The level of significance was $p < 0.05$. Data analysis was performed using SPSS (version 21, SPSS Inc., Chicago, IL, USA).

Results

Figure 3 shows the CMJ performance for the whole group as well as the performance of both RG and NRG at pre-test and post-test. Cluster analysis showed the differences between those participants who experienced a significant level of PAP in the CMJ during the testing session (RG, n = 25 [16 men and 9 women], +0.03 m, $p < 0.001$), and those participants who did not experience PAP in the CMJ (NRG, n = 8 [4 men and 4 women], −0.014 m, $p = 0.017$). Significant differences between pre- and post-test were also found in the whole group ($p = 0.002$). Additional information about demographic characteristic, body composition and physical fitness of participants is given in Table 1. Student's t-test showed no significant difference ($p \geq 0.05$) in any variable analysed between RG and NRG. No significant differences between RG and NRG were also found in comparing variables related to exhaustion level reached during the assessment protocol (HRpeak, HRmean and RPE), whilst HRrec was significantly different between both groups ($p = 0.004$) (Table 2). The intra- and inter-observer reliabilities were calculated for each of the CMJ instants included within this study. Regarding the inter-observer reliability, ICC values above 0.990 were obtained at any CMJ moment; whilst intra-observer reliability showed ICC values above 0.985 (Table 3).

[Figure 3 near here]

[Table 2 near here]

[Table 3 near here]

A comparative analysis of variables related to jumping kinematics before and after running protocol (pre-post) is shown in Table 4. Regarding between-group comparison (RG and NRG), no significant differences ($p \geq 0.05$) were found in any of variables analysed at any moment of the CMJ analysis, apart from Δβankle3 ($p = 0.013$). As for the within-group comparison, neither RG nor NRG showed significant changes at post-test according to pre-test values ($p \geq 0.05$).

[Table 4 near here]

Discussion and implications

The purpose of this study was to determine whether kinematic data during CMJ might explain PAP phenomenon after an exhausting running test. The results obtained partially rejected the initial hypothesis from the authors so that improvements observed in CMJ performance—that is, the PAP phenomenon—were not reflected in the manner by which athletes jumped (jumping kinematic), despite high exhaustion levels reached during the assessment protocol (HRpeak: 189 bpm, HRmean: 164 bpm, RPE: 16). The running protocol performed did not cause significant kinematic changes in either RG or NRG. Additionally, no differences were obtained between both RG and NRG in any variable related to CMJ performance (concentric and eccentric phases prior to flight time: neither joint angles nor tecc and tconc). Nevertheless, during landing some differences between groups were found (not always statistically significant) which might be related to injury risk (Richards et al., 1996; Ryan et al., 2006). θknee and θankle at initial ground contact increased in NRG at post-test (+4.5 and +6.70°, respectively) whilst they reduced in RG (−2.43 and −3.91°). Likewise, at the deepest position during landing, the reduction of θhip and θknee at post-test was greater in RG (–9.55 and –4.85°, respectively) than in NRG (–0.52 and –0.19).

The CMJ is a key performance requirement in many sports. Research has shown positive relationships between lower limb strength and power measures and CMJ performance (Bosco et al., 1986; Buchheit, Spencer, & Ahmaidi, 2010; Nagano, Komura, Fukashiro, & Himeno, 2005; Pruyn, Watsford, & Murphy, 2014; Salles et al., 2011). Specifically, jumping tests are also commonly used with endurance runners, to assess both the acute effects of workouts at the neuromuscular level (García-Pinillos et al., 2015; Gorostiaga et al., 2010; Vuorimaa et al., 2000) and the effectiveness of training protocols on lower body power (Paavolainen, Hakkinen, Hamalainen, Nummela, & Rusko, 1999; Saunders et al., 2006). After any conditioning activity, mechanisms of muscular fatigue and PAP coexist, and so subsequent power output and performance depend on the balance between these two factors. Some previous papers have informed about PAP in sprint or vertical jumps after performing exercises with external loads or resistance (Esformes, Cameron, & Bampouras, 2010; Hamada, Sale, & Macdougall, 2000; Requena et al., 2011). However, to the best of the researchers' knowledge, to date, a limited number of studies have investigated running exercises to elicit PAP in explosive movements, such as CMJ (Boullosa & Tuimil, 2009; Boullosa et al., 2011; García-Pinillos et al., 2015; Gorostiaga et al., 2010; Latorre-Román et al., 2014; Vuorimaa et al., 2006) and none of them have analysed jumping kinematics and its possible relationship with the acute enhancement of jumping performance.

Few researchers have compared kinematic determinants of CMJ performance and there are discrepancies among the results of these few studies investigating ankle, knee and hip joint contributions during the CMJ. Hubley and Wells (1983) found the greatest contributor was the knee joint, whilst Fukashiro and Komi (1987) found it was the hip joint. More recently, Vanezis and Lees (2005) obtained values that were in closer agreement with Fukashiro and Komi (1987) than with Hubley and Wells (1983). Countermovement depth has also been linked to CMJ performance. Knee flexion angle during the descent phase (countermovement prior to take- off) of the CMJ is an important biomechanical variable that influences the outcome of the CMJ (Petushek et al., 2012). Moran and Wallace (2007) found that increasing the knee joint range of motion from 70° to 90° resulted in a 17% improvement in CMJ height. Similarly, high ankle dorsi-flexion range of motion has been shown to contribute to CMJ performance (Georgios, Fotis, Thomas, Vassilios, & Iraklis, 2007). As we mentioned earlier, no differences were found between RG and NRG in the aforementioned variables linked to CMJ performance, so fatigue- induced changes in jumping kinematic after an incremental running test do not explain the PAP phenomenon in endurance runners.

Some previous studies have directly focused on this topic and, although it might be expected that differences in CMJ performance were reflected in the manner of jumping, the results obtained in this study support some prior findings. Rodacki, Fowler, and Bennett (2002) reported that fatiguing the knee flexor muscles did not significantly change the kinematic or kinetic variables at any joint level, during either the negative or positive phases of the movement. Likewise, Pereira et al. (2014) concluded that fatigue does not change the segment contributions and segmental synergies, regardless of the reduction in jumping height. Hence, this study supports those statements and adds that kinematic variables linked to CMJ performance do not explain nor justify PAP phenomenon, at least under these conditions. The authors suggest that, under fatigue (defined as the inability of the neuromuscular system to sustain the required or expected power output around a joint (Enoka & Duchateau, 2008)), compensatory strategies may induce a reorganisation of the movement structure and a new coordination pattern may appear, letting athletes maintain CMJ performance despite high levels of exhaustion. This rationale is in agreement with other studies (Bonnard, Sirin, Oddsson, & Thorstensson, 1994; Pereira et al., 2014; Rodacki et al., 2002), which provide evidence that some compensatory mechanisms are used to counter- balance the loss of the muscle force-generating properties because of fatigue.

Additionally, the results of this study show differences in HRrec between RG and NRG so that, PAP capacity might be related to cardiac recovery. Since HRrec has been described as an indicator for functional adaptation in trained participants in endurance sports (Otsuki et al., 2007), this finding could indicate that runner's ability of achieving PAP after an incremental exercise running test is related to training adaptations in endurance athletes. More research is needed to highlight this initial hypothesis.

Three-dimensional motion analysis has been the 'gold standard' in kinematic analysis and the authors are aware that it is the main limitation of this study. However, this method relies on multiple expensive cameras and time-intensive set-up procedures whilst two-dimensional motion analysis relies on fewer cameras than 3D, which reduces cost and set-up time. Hence, notwithstanding these limitations, the current field-based study offers some insight into PAP phenomenon in endurance runners.

Conclusions

This study shows kinematic data during CMJ do not explain PAP phenomenon after an exhausting running test in endurance runners. From a practical point of view, this study helps to understand how accumulated fatigue during an incremental running test affects certain parameters that have been linked to CMJ performance and rejects the hypothesis that kinematic variables are determinant of PAP phenomenon in endurance runners.

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Disclosure statement

None of the authors have any financial interest or benefit arising from the direct applications of their research.

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