International Journal of EXERCISE SCIENCE

Original Research

Different Barbell Height Positions Affect Maximal Isometric Deadlift Force and Subsequent Squat Jump Performance in Recreationally-Trained Men

JONATHAN MONTANO†[1], ELIZABETH TOROSSIAN†[1], VINCENT G.F. MARTINEZ†[1]; LERAN LHANIE*[1]; SHAHAN AWAKIMIAN*[1]; CHARLES R. LOPES‡[2,3]; PRISCYLA N. MARCHETTI‡[1], and PAULO H. MARCHETTI‡[1]

[1]Department of Kinesiology, California State University-Northridge, Northridge, CA, USA; [2]Human Movement Sciences Graduate Program, Methodist University of Piracicaba, SP, BRAZIL; [3]Adventist Faculty of Hortolandia, Hortolandia, SP, BRAZIL

*Denotes undergraduate student author, †Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 14(4): 1247-1255, 2021. The primary purpose of this study is to examine the effect of two different deadlift barbell height positions on maximal isometric force and subsequent maximal squat jump performance in recreationally-trained men. Fifteen young, healthy, recreationally-trained men (age: 24.7 ± 3.5years, height: 177.1 ± 7.9cm, and total body mass: 81.2 ± 9.8kg) volunteered to participate. All participants performed maximal squat jumps (MSJ) at 90º of knee flexion before (pre-test) and after 4-min (post-test) performing the deadlift exercise using maximal isometric force (MIF) and MIF normalized by body mass ($ratio_{MIF}$) in two barbell height positions (25% and 75% of the lower limb height, LLH) in a randomized and counterbalanced order. A paired-sample t-test was used to test differences in MIF and $ratio_{MIF}$ between 25% LLH and 75% LLH. Two-way ANOVAs were used for positions (25% LLH and 75% LLH) and time (pre- and post-test) for all dependent variables with an alpha of 5%. Differences were found for MIF and $ratio_{MIF}$ during the deadlift between 25% LLH and 75% LLH ($p < 0.001$). There was observed an increase in impulse between pre- and post-test only at 75% LLH ($p < 0.001$), decrease in time to peak force between pre- and post-test only at 75% LLH ($p < 0.001$), and increase in peak force between pre- and post-test at 75% LLH ($p = 0.029$). The present results showed that the maximal isometric deadlift exercise at 75% LLH (midthigh) improves subsequent jump performance of the squat jump recreationally-trained men.

KEY WORDS: Squat jump, strength, isometric mid-thigh pull

INTRODUCTION

Warm-up is a fundamental component to prepare athletes before a higher muscle demand, mainly, before competition or sports events (2). Different warm-up strategies are used to prepare athletes to enhance their power/strength performance, such as stretching (ballistic or dynamic), low-intensity cyclical activities (steady jogging, running, or cycling), isometric actions, and/or activities that mimic sporting movements progressing from low to high-intensity speed (2, 18).

Additionally, post-activation performance enhancement (PAPE) is a phenomenon frequently used as part of the specific warm-ups aiming to improve power/strength performance following maximal or near-maximal static (12, 14, 15, 26, 28) or dynamic contractions (3, 5, 11). PAPE is characterized by an increase in power after a conditioning activity based on several mechanisms (reduction of neuronal rheobase, rise in myosin light chain phosphorylation, greater activation of fast fibers, the influence of the pennation muscle, increased cytosolic concentration of inorganic phosphate, and the enzymatic stimulation: calcium/calmodulin)(27).

Isometric actions can be used quickly before competitions and sports events, as part of the specific warm-up, aiming to induce PAPE in various short-term power activities. Specifically, multijoint isometric exercises are used to evaluate the maximum force and rapid force-generating capacity in athletes (7, 8, 9). Beckham et al., (6) analyzed fourteen powerlifters who performed isometric deadlift pulls on a force plate at 3 key positions (at the floor, just above the patella, and 5-6 cm short of lockout) and in the midthigh pull position. The authors reported the force generated in the midthigh pull position was significantly higher than any other position. Bartolomei et al., (4) analyzed twenty experienced resistance-trained men (3 years of experience) on maximal isometric deadlift force in two barbell positions (midthigh and mid shin) performed on a force plate.

Several studies analyzed the effects of isometric actions on subsequent PAPE with controversial results (12, 14, 15, 26, 28). A study by French et al. (12) and Gullich and Schmidtbleicher (15) showed that isometric actions improved power activities (counter-movement jumps and drop jump height). On the other hand, Gossen and Sale (14) and Robbins and Docherty (26) did not observe differences in dynamic knee extension or counter-movement jump (respectively) after maximal isometric actions. Additionally, Tsolakis et al. (28) observed that stronger individuals showed a greater decrease in peak leg power after isometric actions. Besides, performing maximal isometric actions with a specific body position may offer a better mechanical advantage to produce power/strength (4) and, consequently, induce PAPE. To the best of the authors' knowledge, no study analyzed the influence of the body position on subsequent PAPE phenomenon.

Therefore, the purpose of this study is to examine the effect of two different deadlift barbell height positions on maximal isometric force and subsequent maximal squat jump performance in recreationally-trained men. Based on a pilot study, it is hypothesized that 1. the higher barbell position has greater effects on the maximal isometric force during the deadlift exercise and 2. the maximal isometric force with the higher barbell position induces greater enhancement in the subsequent maximal squat jump performance. Thus, understanding the effect of maximum isometric force on jump performance can be useful in the use of more effective and faster specific warm-up strategies for athletes in various high intensity and short duration sports such as rugby, volleyball, handball, football, track & field (sprints, throws, and jumps), power/strength sports (weightlifting and weightlifting), and combat sports.

METHODS

Participants

The sample size was justified by a priori power analysis based on a pilot study where the maximal impulse of the vertical jump, in four recreationally-trained participants, was assessed as the outcome measure with an effect size difference of 0.70, an alpha level of 0.05, and a power ($1 - \beta$) of 0.80 (10). Therefore, fifteen young, healthy, recreationally-trained men (age: 24.7 ± 3.5 years, height: 177.1 ± 7.9cm, and total body mass: 81.2 ± 9.8kg) volunteered to participate. All participants had previous experience of resistance training for at least 1 year and a frequency of three times a week. Participants had no previous lower back injuries, surgery on their lower extremities, and no history of injury with residual symptoms (pain, "giving-away" sensations) in their lower limbs within the last year. The participants were informed of the risks and benefits of the study prior to any data collection and then read and signed an institutionally approved the informed consent document and the study (#1718/161-2018). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (22).

Protocol

All procedures were randomized and counterbalanced across participants and experimental conditions. Participants attended one session in the laboratory and refrained from performing any lower body exercise other than activities of daily living for at least 48 hours prior to testing.

The participants' anthropometric measurements (height, weight, and lower limb length) were measured. The lower limb length in standing position was used to determine two different barbell height positions (25% and 75% of lower limb height [LLH]). The lower limb length was measured from the greater trochanter of the femur to the lateral malleolus of the fibula. Next, each participant performed a standardized dynamic warm-up consisting of 5 submaximal squat jumps (starting at 90º of knee flexion). Afterward, all participants performed a familiarization with the deadlift exercise using three trials of 2-sec submaximal isometric actions in two different barbell height positions (25% LLH and 75% LLH) using a locked barbell. The participants' feet were positioned at hip-width apart in a comfortable position, vertically aligned with the barbell position, and marked by a tape on the floor. The participants' grip was marked on the barbell using tape in a comfortable position. The same hand and feet positioning were used in all experimental conditions.

After a specific warm-up and familiarization, all participants performed a pre-test with three trials of the maximal squat jump (MSJ) (starting at 90º of knee flexion), no arm action (hands on the hips), and 30-sec of rest between trials. A step (with height adjustment) was positioned behind each participant in order to restrict the initial position of the knees (at 90º of knee flexion) before all MSJs and to avoid the countermovement. Then, participants performed the maximal isometric deadlift exercise (MIF) with three trials of 5-sec against a locked barbell under one of two barbell height positions in a randomized and counterbalanced order: (1) MIF at 25% LLH; or (2) MIF at 75% LLH. A 30-sec rest interval was permitted between trials. After all MIFs at one specific barbell height position (25% LLH or 75% LLH), all participants rested for 4-minutes, and they were asked to perform three trials of MSJ (post-test) (starting at 90º of knee flexion), with 5-

sec of rest between trials. In the same session, all participants rested for 45-minutes, and then, they repeated all procedures with a different height barbell position (25% LLH or 75% LLH), Figure 1.

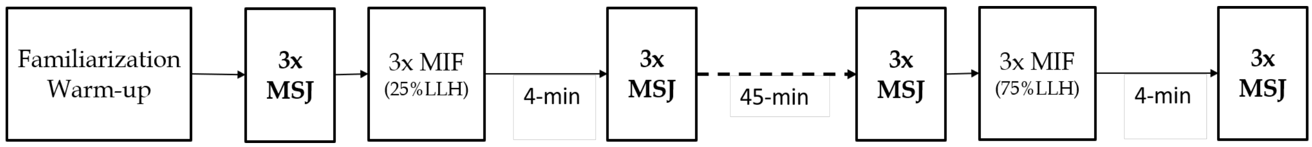

Figure 1. Experimental Procedure.
Legend: MSJ – maximal squat jump; MIF - maximal isometric deadlift exercise; LLH - lower limb height; min – minutes.

The MIFs (25% LLH and 75% LLH) and all MSJs were performed on a force plate (Kistler, Kistler Instrument Corp., NY, USA) with a sample rate at 250Hz. All participants were asked to wear the same shoes during the session and to maintain their normal dietary intake. They also received similar verbal encouragement during all trials, all measurements were performed between 2 PM and 4 PM, and measured by the same researcher (CSCS certified).

The vertical ground reaction force data (vGRF) were analyzed with a customized Matlab routine (MathWorks Inc., Massachusetts, USA).

Maximal isometric force (MIF): The digitized vGRF data from the deadlift exercise were low-pass filtered at 10Hz using a fourth-order Butterworth filter with a zero lag. Then, the first and last second was removed to avoid body adjustments. Then, the MIF was defined as the maximal value of three trials in each barbell height position (25% LLH and 75% LLH). The MIF was normalised by the body weight ($ratio_{MIF}$) for both barbell height positions, was calculated as follows: $Ratio_{MIF}$ = MIF (N)/body mass (kg)*9.81.

Maximal Squat Jump (MSJ): The digitized vGRF data from each MSJ was filtered using a fourth-order Butterworth filter with a 10 Hz cutoff frequency, and zero lag. Then, three dependent variables were analyzed: 1. Peak force (PF) was defined as the maximal value of the force x time curve (concentric phase); 2. Time to peak force (TPF) was defined as the time between the beginning of the jump (concentric phase) and the peak force; 3. Impulse was defined as the area under the force-time curve, defined by the beginning of the jump (concentric phase) and the take-off (16, 20, 21). The average of three MSJs was calculated for each jump variable and used for further analysis.

Statistical Analysis
The normality and homogeneity of variances were confirmed by the Shapiro-Wilk and Levene's tests, respectively. Mean, standard deviation, delta percentage (Δ%), and 95% confidence interval (CI) were calculated. A paired-sample t-test was used to test differences in MIF and $Ratio_{MIF}$ between two deadlift barbell height positions (25% LLH or 75% LLH). The data from the MSJ were analyzed with two-way repeated-measures ANOVA with two barbell height positions (25% LLH and 75% LLH) and times (pre- and post-test) for all dependent variables

(Peak Force, TPF, and Impulse). Post-hoc comparisons were performed with the *Bonferroni* test. Furthermore, the magnitudes of the difference were examined using the standardized difference based on Cohen's d units using effect sizes (*d*). The *d* results were qualitatively interpreted using the following thresholds: < 0.35 - trivial; 0.35-0.8 - small; 0.8-1.5 - moderate; > 1.5 - large for recreationally trained (25). An alpha of 5% was used to determine statistical significance.

RESULTS

Maximal isometric force (MIF) during the deadlift exercise: For MIF, there was a statistical difference between barbell positions (25% LLH: 1873.0 ± 715.9N vs. 75% LLH: 2278.6 ± 741N, $p < 0.001$, $d = 0.56$ [small effect], and Δ% = 18%). For $Ratio_{MIF}$ there was a statistical difference between barbell positions (25% LLH: 2.42 ± 1.1 vs. 75% LLH: 2.94 ± 1.1, $p < 0.001$, $d = 0.47$ [small effect], and Δ% = 17.7%).

Squat Jump Variables: For PF, there was a significant main effect for time ($p = 0.040$). There was interaction between barbell height position and time ($p = 0.007$). There was observed statistical increase for PF between pre- and post-test at 75%LLH ($p = 0.029$, $d = 0.97$ [moderate effect], and Δ% = 15) (Figure 2a). For TPF, there was no significant main effect for barbell height position ($p = 0.173$) or time ($p = 0.240$). There was interaction between barbell height position and time ($p = 0.012$). There was observed statistical decrease for TPF between pre- and post-test only at 75% LLH ($p < 0.001$, $d = 0.77$ [small effect], and Δ% = 25) (Figure 2b). For Impulse, there was a significant main effect for time ($p < 0.001$). There was interaction between barbell height position and time ($p = 0.025$). There was observed statistical increase in impulse between pre- and post-test only at 75% LLH ($p < 0.001$, $d = 0.41$ [small effect], and Δ% = 18%) (Figure 2c).

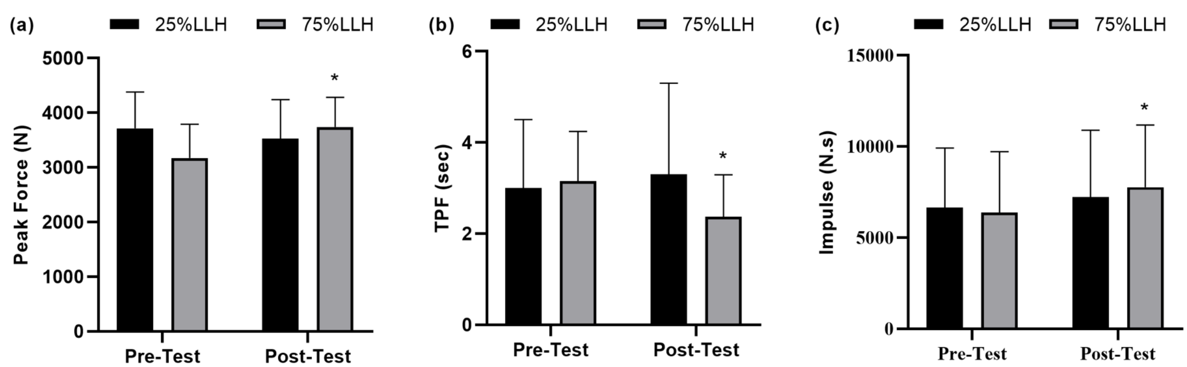

Figure 2. Mean ± standard deviation of (a) peak force; (b) time to peak force (TPF); and (c) impulse of the maximal squat jump before and after maximal isometric deadlift with different lower limb heights (25% and 75% LLH). Note. *Significant difference between pre- and post-test, $p<0.05$.

DISCUSSION

The purpose of this study is to examine the effect of two different deadlift barbell height positions on maximal isometric force and subsequent maximal squat jump performance in recreationally-trained men. The main findings of this study were that: 1. the high barbell position (75% LLH) produced higher values of MIF and $ratio_{MIF}$ during the deadlift exercise when compared to the lower barbell position (25% LLH); 2. The maximal isometric deadlift exercise at 75% LLH affected positively the squat jump performance. These results can be useful in the use of more effective and faster specific warm-up strategies for athletes in various high intensity and short duration sports.

Multijoint isometric exercises are used to evaluate the maximum force and rapid force-generating capacity in athletes (7, 8, 9). The results for the maximal isometric force (MIF) showed that the high barbell position (75% LLH) produced higher values (18%) when compared to the low barbell position (25% LLH) during the deadlift exercise and corroborated with our hypothesis that the higher barbell position has greater effects on maximal isometric actions during the deadlift exercise [75% LLH: 2,278.6 ± 741.0N ($ratio_{MIF}$ = 2.94 ± 1.1) and 25% LLH: 1,873.0 ± 715.9N ($ratio_{MIF}$ = 2.42 ± 1.1), $p < 0.001$]. Additionally, the studies of Beckham et al., (6) and Bartolomei et al., (4) corroborated with the present results, however with different training statuses. Beckham et al., (6) analyzed fourteen powerlifters who performed isometric deadlift pulls on a force plate at 3 key positions (at the floor, just above the patella, and 5-6 cm short of lockout) and in the midthigh pull position. The authors reported the force generated in the midthigh pull position (5,829.0 ± 867.0N) was significantly higher than any other position. Bartolomei et al., (4) analyzed twenty experienced resistance-trained men (3 years of experience) on maximal isometric deadlift force in two barbell positions (midthigh and mid shin) performed on a force plate. Regarding all previous studies, at 75% LLH (or midthigh) position favored the participants to produce the highest maximal isometric force during the deadlift exercise. The greater level of force observed at 75% LLH may be explained by a greater mechanical advantage in this position (promoting a greater internal moment arms and ideal jumping position) when related to 25% LLH (or mid shin) position. Additionally, in this specific position (at 25% LLH), it is feasible to speculate that changes in muscle length modify muscle contractile abilities and, may modify sEMG (superficial electromyography)-force and sEMG-moment relationships (1, 19, 24, 30). Afferent signals from muscles could decrease motoneuronal firing frequency (i.e. Golgi tendon reflex, GTO) during isometric actions when the muscle fibers are in an elongated position (13).

Regarding the subsequent effect in jump performance after the maximal isometric deadlift exercise with two barbell positions, the results of the present study showed that only the deadlift exercise at 75% LLH affected positively the MSJ performance corroborating the hypothesis that maximal isometric actions with higher barbell position will induce a greater enhancement in subsequent squat jump performance. The dependent variables analyzed in the present study were peak force (PF), time to peak force (TPF), and impulse. For the 75% LLH position, the PF increased by 15% resulting in greater force production during the MSJ and the TPF decreased by 25% representing a faster movement during MSJ. The combination of these two variables represents the rate of force development that is a fundamental component of jump performance. Additionally, the capacity to jump is dependent on the velocity of take-off and attributable to impulse (impulse-momentum relationship) (29), thus, in the present study impulse increased by 18% after the deadlift exercise at 75% LLH.

The results presented in this study might be explained by the post-activation performance enhancement (PAPE). PAPE is characterized by an increase in power after a conditioning activity based on several mechanisms (reduction of neuronal rheobase, rise in myosin light chain phosphorylation, greater activation of fast fibers, the influence of the pennation muscle, increased cytosolic concentration of inorganic phosphate, and the enzymatic stimulation: calcium/calmodulin) (27). The results of this study showed improvement in jump performance after maximal isometric actions using the deadlift exercise in all variables analyzed and corroborated with studies that showed scientific evidence of the use of isometric actions in increasing strength/power activities (12, 15). Curiously, only the deadlift exercise at 75% LLH affected the subsequent squat jump performance. A possible explanation for these results may be the difference in peak force observed between the two analyzed positions (75% LLH > 25% LLH, Δ% = 17.7%). The greatest results in peak force have greater effects on PAPE or it can be hypothesized that there is a certain minimum threshold of force to produce PAPE for each task, although this hypothesis has not been tested in the present study. Another possible explanation for these results might be the relationship between the deadlift position and the initial squat jump position. The transfer of force from isometric actions to tasks at similar joint angles is documented in the scientific literature (17). In this way, maximal isometric actions at specific joint positions during multi-joint exercises (deadlift) can provide mechanical specificity (23).

The results showed that the isometric deadlift exercise at 75% LLH improves the subsequent jump performance on recreationally-trained men. The present findings suggest the use of isometric actions at a specific joint angle combined with a multi-joint exercise (deadlift) is efficient to improve jump performance. This research may be of benefit to different athletes and practitioners of various sports such as rugby, volleyball, handball, football, track & field (sprints, throws, and jumps), power/strength sports (weightlifting and weightlifting), and combat sports. Maximal isometric actions at a specific joint angle combined with multi-joint exercises can be used as part of a specific warm-up aiming at the subsequent increase in jumping performance. In addition, isometric actions can be used quickly before competitions and when other high-intensity strategies are not available.

This study has some limitations that should be considered when interpreting the current results. We did not measure the joint angles during the deadlift exercise in both isometric conditions. We analyzed two conditions (25% LLH and 75% LLH) in the same session with 45-min rest between conditions, even not observing residual fatigue between conditions. We also used healthy, recreationally-trained men only, and, therefore, our findings are not generalizable to other conditions, populations, or women. Future studies could evaluate the effect of isometric actions in different jumps, populations, and with different times between isometric action and jumps.

ACKNOWLEDGEMENTS

The authors thank the participants for their participation and the Biomechanics Laboratory at California State University-Northridge.

REFERENCES

1. Ahn N, Kim H, Krzyszkowski J, Roche S, Kipp K. Influence of the bar position on joint-level biomechanics during isometric pulling exercises. J Strength Cond Res 35(6): 1484-1490, 2021.

2. Andrade DC, Henriquez–Olguín C, Beltrán AR, Ramírez MA, Labarca C, Cornejo M, Álvarez C, Ramírez-Campillo R. Effects of general, specific, and combined warm-up on explosive muscular performance. Biol Sport 32(2): 123-128, 2015.

3. Arias J, Coburn J, Brown L, Galpin A. The acute effects of heavy deadlifts on vertical jump performance in men. Sports 4: 1-8, 2016.

4. Bartolomei S, Rovai C, Lanzoni IM, di Michele R. Relationships between muscle architecture, deadlift performance, and maximal isometric force produced at the midthigh and midshin pull in resistance-trained individuals. J Strength Cond Res Epub ahead of print doi: 10.1519/JSC.0000000000003455, 2019.

5. Bauer P, Sansone P, Mitter B, Makivic B, Seit L, Tschan H. Acute effects of back squats on countermovement jump performance across multiple sets of a contrast training protocol in resistance-trained males. J Strength Cond Res 33(4): 995-1000, 2018.

6. Beckham GK, Lamont HS, Sato K, Ramsey MW, Stone MH. Isometric strength of powerlifters in key positions of the conventional deadlift. J Trainol 1 :32-35, 2012.

7. Brady CJ, Harrison AJ, Comyns TM. A review of the reliability of biomechanical variables produced during the isometric mid-thigh pull and isometric squat and the reporting of normative data. Sports Biomech 19: 1-25, 2020.

8. Chiu LZF. Biomechanical methods to quantify muscle effort during resistance exercise. J Strength Cond Res 32(2): 502-513, 2018.

9. Comfort P, Dos'Santos T, Beckham GK, Stone MH, Guppy SN, Haff GG. Standardization and methodological considerations for the isometric midthigh pull. Strength Cond J 41(2): 57-79, 2019.

10. Eng J. Sample size estimation: How many individuals should be studied? Radiol 227(2): 309-313, 2003.

11. Esformes JI, Bampouras TM. Effect of back squat depth on lower-body postactivation potentiation. J Strength Cond Res 27(11): 2997-3000, 2013.

12. French DN, Kraemer WJ, Cooke CB. Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. J Strength Cond Res 17(4): 678-685, 2003.

13. Gardiner PF. Advanced neuromuscular exercise physiology. Champaign, IL: Human Kinetics; 2011.

14. Gossen ER, Sale DG. Effect of postactivation potentiation on dynamic knee extension performance. Eur J Appl Physiol Rep 83(6): 524-530, 2000.

15. Gullich A, Schmidtbleicher D. Mvc-induced short-term potentiation of explosive force. N Stud Athlet 11(4): 67-81, 1996.

16. Kirby TJ, McBride JM, Haines TL, Dayne AM. Relative net vertical impulse determines jumping performance. J Appl Biomech 27(3): 207-214, 2011.

17. Lum D, Barbosa TM. Brief review: Effects of isometric strength training on strength and dynamic performance. Int J Sports Med 40(6): 363-375, 2019.

18. Lum D, G. Gregory Haff GG, Barbosa TM. The relationship between isometric force-time characteristics and dynamic performance: A systematic review. Sports (Basel) 8(5): 63, 2020.

19. Marchetti PH, Da Silva JJ, Schoenfeld BJ, Nardi PSM, Pecoraro SL, Greve JMD, Hartigan E. Muscle activation differs between three different knee joint-angle positions during a maximal isometric back squat exercise. J Sports Med 2016: 3846123, 2016.

20. McBride JM, Kirby TJ, Haines TL, Skinner J. Relationship between relative net vertical impulse and jump height in jump squats performed to various squat depths and with various loads. Int J Sports Physiol Perform 5(4): 484-496, 2010.

21. Moir GL. Three different methods of calculating vertical jump height from force platform data in men and women. Meas Phys Educ Exerc Sci 12(4): 207-218, 2008.

22. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

23. Ng CY, Chen SE, Lum D. Inducing postactivation potentiation with different modes of exercise. Strength Cond J 42(2): 63-81, 2020.

24. Prilutsky BI. Coordination of two- and one-joint muscles: Functional consequences and implications for motor control. Motor Control 4(1): 1-44, 2000.

25. Rhea MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. J Strength Cond Res 18(4): 918-920., 2004.

26. Robbins DW, Docherty D. Effect of loading on enhancement of power performance over three consecutive trials. J Strength Cond Res 19(4): 898-902, 2005.

27. Tillin NA, Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. Sports Med 39(2): 147-166, 2009.

28. Tsolakis C, Bogdanis GC, Nikolaou A, Zacharogiannis E. Influence of type of muscle contraction and gender on postactivation potentiation of upper and lower limb explosive performance in elite fencers. J Sports Sci Med 10: 577-583, 2011.

29. Winter EM. Jumping: Power or impulse? Med Sci Sports Exerc 37(3): 523, 2005.

30. Worrell TM, Karst G, Adamczyk D, Moore R, Stanley C, Steimel B, Steimel S. Influence of joint position on electromyographic and torque generation during maximal voluntary isometric contractions of the hamstrings and gluteus maximus muscles. J Orthop Sports Phys Ther 31(12): 730-740, 2001.