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Voluntary Muscle Relaxation Can Mitigate Fatigue and Improve Countermovement Jump Performance

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Abstract

Pinto, BL and McGill, SM. Voluntary muscle relaxation can mitigate fatigue and improve countermovement jump performance. *J Strength Cond Res* 34(6): 1525–1529, 2020—When muscles contract, they create force and stiffness. Thus, muscle activation and relaxation must be strategically sequenced to coordinate and control movement, to enhance athletic variables such as speed and strength. However, research has favored investigation of muscle activation over relaxation. Athletes such as runners, swimmers, and boxers often shake their limbs to allow the muscle to oscillate freely, immediately before a bout. The purpose was to investigate whether shaking the lower limbs with the intention to voluntarily relax the muscles of the limb has an effect on countermovement jump (CMJ) performance. Subjects performed 10 maximal effort CMJs with 30 seconds of rest between each jump. During the rest period, they either performed the relaxation technique or control condition (standing still). Statistical significance was considered at $p < 0.05$. Subjects significantly improved jump height, compared with their first jump of the day, when performing the relaxation technique. To further investigate the mechanism of enhancement, subjects were grouped into responders and nonresponders. The responder group significantly decreased their jump height and concentric phase impulse (relative to the first jump) during the control condition compared with the nonresponder group, indicating fatigue. When performing the relaxation technique, the responder group improved their jump height and mitigated fatigue by significantly increasing their unweighting impulse and unweighting force. The relaxation technique improved CMJ performance, specifically in those that fatigue with consecutive bouts, by enhancing unweighting, that requires muscle relaxation, rather than propulsion that requires activation. This technique can be useful for training or competition.

Key Words: kinetic, unweighting, relaxation technique, rest, shake

Introduction

Given that muscle activation creates both force and stiffness, muscle activation and relaxation need to be appropriately modulated to coordinate and control movement and enhance performance that requires strength and speed (18). Inappropriate modulation of muscle activation and relaxation compromises coordination and control of movement as observed in many movement disorders. Voluntary muscle relaxation, in particular, is impaired in cases such as dystonia (1,31) and after stroke (2,21,25). Compromise of voluntary muscle relaxation can also be related to severity in Parkinson's disease (5,9,13,22). By contrast, when the modulation of muscle activation/relaxation is optimized, maximal power production can be achieved (6). Given the influence of both force and stiffness, speed of limb movement requires activation of muscles in pulses followed with rapid relaxation to allow for high rates of limb movement. For example, pulsing to enhance both closing velocity of the terminal limb to the target and strike impact force (17). Other athletes enhance storage and recovery of elastic energy by strategically creating a tuned stiffness through the body linkage (18). Superior athletic performance has been linked to rate of muscle relaxation (e.g., Olympic weightlifters) (16).

It seems that muscle relaxation does not improve by the same mechanisms that improve muscle activation, such as resistance training (10,11). Investigations on practicing muscle relaxation indicate improvements in anxiety (4), mental health, and quality of life in cancer (12,14), depression and anxiety in those with schizophrenia (3), symptoms in those with somatoform disorder (24), and improvements in depression, anxiety, and length of hospital stay in patients with breast cancer (32). However, little is known about the effects of muscle relaxation training on physical performance. Thus, we were motivated to perform this study to explore the immediate effects of muscle relaxation on performance.

The purpose of this investigation was to quantify whether shaking the lower limbs with the intention to voluntarily relax the muscles of the limb has an effect on countermovement jump (CMJ) performance. It was hypothesized that performing the relaxation technique of shaking the legs and allowing the muscle to oscillate freely would improve jump height, impulse, and force production. Elite athletes such as runners, swimmers, and boxers preparing to compete often shake their limbs to allow the muscle to oscillate freely.

Methods

Experimental Approach to the Problem

A CMJ contains elements of both activation and relaxation during movement. Subjects performed 10 maximal effort CMJs on 2 different occasions (control and intervention day, randomly assigned). The calculated performance variables from each jump were normalized to the variables from the first jump of the day. This would allow for a within-subject and a within-day comparison of performance without confounding variables such as between day recovery, adaptation, and lifestyle factors.

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Subjects

Healthy volunteers included 11 men (mean ± *SD* age 24 ± 2.8 years; mass 83.5 ± 13.3 kg; height 178.6 ± 9.9 cm). Exclusion criteria were no current injury, no history of chronic lower-limb or back injuries, and answering "yes" to any of the questions on the Physical Activity Readiness Questionnaire (PAR-Q). A brief questionnaire on training history and current activity level was completed. Subjects provided written informed consent. All procedures were approved by the University of Waterloo research ethics board.

Procedures

Subjects attended 2 sessions, each at least 24 hours apart in a test, retest design. They were randomly assigned to either the relaxation technique condition (limb shaking) or the control condition (no limb shaking) on the first day and performed the alternate condition on the second day.

Subjects performed 10 maximal effort CMJs with arms crossed at the chest to control for changes in center of mass. Rest periods were controlled to 30 seconds between jumps during which the subject performed either the relaxation technique or the control condition. For the relaxation technique condition, subjects were instructed to allow their thigh muscles to oscillate freely and wobble side to side as they shook their leg. This is akin to shaking water off the leg. The instructed technique required the subject to shake their leg with a bent knee and raised heel while keeping their toe planted in the ground. To do this, they leaned on the opposite leg while shaking. Subjects were allowed to alternate between shaking each leg, at a self-selected pace and intensity, for a total of 30 seconds. The relaxation technique was demonstrated, and a brief practice took place, before any trials began on the day that they were assigned to relaxation technique condition. For the control condition, subjects were instructed to stand and limit any shaking or excessive movement. No additional instruction was given on either day.

Subjects stood on 2 force plates (AMTI ORE6-7 2000) with 1 leg on each force plate. Instruction was given to land in that same fashion. Force was sampled at 2,160 Hz.

All data were low-pass filtered at 100 Hz using a dual-pass second-order (effective fourth order) Butterworth filter. Vertical force data were used to calculate CMJ height as well as impulse, peak force, and duration of each phase of the jump.

Body mass was calculated during the quiet stance phase before the jump and was subtracted from the force before any kinematic or kinetic calculation. Acceleration was calculated by dividing force by mass. Velocity was calculated by integrating acceleration. The onset of the jump was defined as the instant that force decreased below the minimum peak during the quite stance phase, before the jump (20). The onset of the eccentric phase was defined at peak negative (downward) velocity, and the onset of the concentric phase was defined at the instant that velocity exceeded $0\ m{\cdot}s^{-2}$. The point of take-off was defined at the instant where the negative force decreased beyond the body mass of the subject. The phasic interpretation of the force-time curve is depicted in Figure 1.

Jump height was calculated using the vertical velocity at take-off (TOV) as recommended by Moir (20):

$$\text{Height} = \frac{\text{TOV}^2}{2g},$$

Where g is the gravitational constant $9.81\ m{\cdot}s^{-2}$.

Impulse was calculated by integrating the force-time curve and was partitioned into impulse at each of the phases of the jump (unweighting, eccentric, and concentric). Peak force and duration of each phase of the jump were also calculated.

All calculated performance variables were normalized to the first jump of the session to provide meaningful comparison based on daily performances. This would negate any interday differences in the subject's capability to jump.

Statistical Analyses

Mixed factorial repeated-measures analyses of variance were conducted for the normalized CMJ performance variables (dependent variables) for each subject on SPSS 25.0 (IBM Corporation, Armonk, NY). The within-subject independent variables were condition (relaxation technique or control) and trial (jump 1–10).

As with many studies of athletic performance after an intervention, we observed that there were responder and nonresponders. Because we were interested in investigating mechanism and strategy, we created 2 subgroups, specifically responders and nonresponders. This would allow for an analysis of which specific variables enabled performance without confounding influence from those who did not respond. The between-subject factor was group (responder or nonresponder), where responders were defined as subjects whose mean normalized jump height was higher (>0.1% difference) during the relaxation technique than during control. Nonresponders were anyone who decreased (>0.1% difference) in mean jump height during the relaxation technique compared with the control condition. Bonferroni post hoc pairwise comparison testing was completed for any significant variables or interactions. Statistical significance was considered at $p \le 0.05$. Partial eta-squared (η^2) and 95% confidence intervals (CIs) of the difference of mean values were calculated for significant variables.

Results

There were significant main effects for condition such that jump height ($p = 0.016$, CI = 0.706, 5.179, $\eta^2 = 0.496$), concentric phase impulse ($p = 0.010$, CI = 0.464, 2.542, $\eta^2 = 0.543$), and concentric phase jump time ($p = 0.027$, CI = 0.600, 7.762, $\eta^2 = 0.437$) where all higher when performing the relaxation technique.

Seven of the 11 subjects increased their mean jump height in response to the relaxation technique, compared with the control day, and were hence grouped as responders (Table 1). There were significant interaction effects for condition × group for jump height ($p = 0.001$, $\eta^2 = 0.752$), unweighting impulse ($p = 0.043$, $\eta^2 = 0.382$), concentric phase impulse ($p < 0.001$, $\eta^2 = 0.767$), unweighting peak force ($p = 0.032$, $\eta^2 = 0.415$), and concentric jump time ($p = 0.025$, $\eta^2 = 0.444$).

Pairwise comparison showed that the responder group significantly decreased their jump height ($p = 0.018$, CI = −22.236, −2.654, $\eta^2 = 0.479$) and concentric phase impulse ($p = 0.016$, CI = −10.602, −1.430, $\eta^2 = 0.495$) during the control condition compared with the nonresponder group. During the relaxation technique condition, the responder group increased their unweighting impulse ($p = 0.018$, CI = 3.044, 24.848, $\eta^2 = 0.482$) and unweighting force ($p = 0.048$, CI = 0.215, 46.070, $\eta^2 = 0.367$) compared with the nonresponder group. The responder

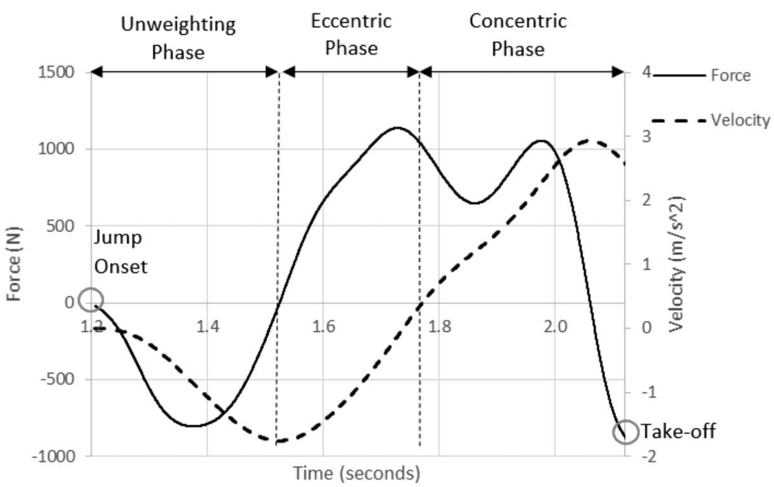

Figure 1. Classification of unweighting, eccentric, and concentric phase from a sample subject's CMJ. The solid line depicts vertical force (Newtons [N]) after subtraction of the subject's body mass. The dashed line depicts velocity (m·s^{-2}). The unweighting phase is defined as the time between the onset of the jump to peak downward velocity, the eccentric phase is defined as the time between peak downward velocity to the instant velocity exceeded 0 m·s^{-2}, and the concentric phase defined as the time between the end of the eccentric phase and take-off. Note that the force is shown from the onset of the jump and the quiet stance phase has been excluded.

group decreased jump height ($p < 0.001$, CI = −10.810, −5.415, $\eta^2 = 0.837$), concentric phase impulse ($p < 0.001$, CI = −5.258, −2.751, $\eta^2 = 0.853$) during the control condition compared with the relaxation technique condition. However, during the relaxation technique condition, they increased concentric phase time ($p = 0.002$, CI = −12.745, −4.108, $\eta^2 = 0.684$) compared with the control condition (Table 2).

The nonresponder group did not significantly change or decrease jump performance between the 2 conditions. Subjects S06 and S09 had the largest decrease in mean normalized jump height during the relaxation technique but still maintained a jump height that was higher than the first jump of the day, by more than 2%. However, they also had the largest increase in jump height during the control condition. Similarly, subject S03 maintained a performance higher than their first jump of the day during the relaxation technique condition, but this was slightly lower than their performance during the control condition. Subject S02 was the only subject to show a decrease in mean jump height below that of the first jump of the day when performing the relaxation technique.

No other variables or interactions were statistically significant. No differences in order in which the protocol was performed or previous athletic training were found between the responder and nonresponder group.

Table 1

Mean ± *SD* normalized jump height across the 10 jumps for each subject.

Subject	Control	Relaxation technique	Difference*
S01	75.60	84.83	9.22
S02	100.18	98.30	−1.87
S03	101.68	101.10	−0.57
S04	94.86	106.48	11.62
S05	93.00	99.49	6.48
S06	105.57	103.09	−2.48
S07	100.79	102.97	2.17
S08	96.14	109.65	13.51
S09	108.30	104.31	−3.98
S10	92.19	99.24	7.05
S11	87.81	94.54	6.73
Average	98.05	101.92	—
SD (±)	6.37	4.35	—

*Difference between the relaxation technique and control condition. Negative values indicate nonresponders.

Table 2

Mean ± *SD* of normalized performance variables for the responder and nonresponder groups averaged across the 10 jumps performed and then across subjects.

	Control		Relaxation technique	
	Mean (%)	SD (±)	Mean (%)	SD (±)
Responder				
Jump height	**91.49***	**8.04**	**99.60**	**8.20**
Unweighting impulse	103.47	8.89	116.61*	9.15
Eccentric impulse	111.40	29.74	115.14	9.71
Concentric impulse	**95.78**	**3.76**	**99.78**	**3.55**
Unweighting peak force	100.02	9.26	118.71*	19.68
Eccentric peak force	105.78	22.09	109.96	7.09
Concentric peak force	100.10	3.84	98.37	8.33
Unweighting time	106.15	13.68	100.36	16.62
Eccentric time	102.89	9.26	99.98	11.30
Concentric time	**99.91**	**8.84**	**108.33**	**7.04**
Nonresponder				
Jump height	103.93*	3.70	101.70	2.62
Unweighting impulse	119.35	25.94	102.67*	3.10
Eccentric impulse	118.65	24.82	102.10	2.64
Concentric impulse	101.80*	1.82	100.80	1.14
Unweighting peak force	122.11	33.10	95.57*	3.16
Eccentric peak force	117.42	18.74	108.49	8.42
Concentric peak force	99.23	5.90	98.78	5.12
Unweighting time	91.86	10.00	98.87	4.94
Eccentric time	87.97	21.52	94.51	6.52
Concentric time	100.47	3.26	100.41	2.04

*Significant pairwise comparisons between groups. Significant pairwise comparisons between conditions are bolded.

Discussion

Studying the behavior of elite performers can give insight into the mechanisms of how the body functions and what it is capable of achieving. Athletes such as runners, swimmers, and boxers often shake their limbs to allow the muscle to oscillate freely, immediately before a bout. Although there may be psychological benefits to performing such an action, the purpose of this investigation was to quantify whether there are any immediate benefits from voluntarily relaxing the lower-limb muscles, by shaking the limbs, between maximal bouts of a CMJ. Our results show that performing a relaxation technique, with the intent to allow the muscles to relax and oscillate freely, before a maximal bout, can improve performance.

Interestingly, those who responded to the relaxation technique decreased their performance during the control condition compared with the relaxation condition (Figure 2) and compared with the nonresponder group. Decreased CMJ performance can be indicative of fatigue (7,8,23,27–29). When performing the relaxation technique, these subjects were able to mitigate fatigue and did not decrease jump height or concentric phase impulse as they did on the control day. Both central and peripheral factors play a role in fatigue. However, this study did not include any outcome measures of fatigue to make conclusions on the mechanisms by which subjects fatigued.

Responders increased their jump height by increasing impulse during the unweighting phase, by increasing peak unloading force compared with the nonresponder group that showed a decrease in unweighting impulse and force. This increase in unweighting allowed the responders to increase their concentric phase time compared with their control condition, resulting in a maintenance of concentric phase impulse and jump height with consecutive bouts. Higher jump heights have been associated with higher impulse and force in the eccentric and concentric phase, creating more propulsion (15,19,26). Conversely, the relaxation drill did not increase propulsive force, but rather increased the downward acceleration (since acceleration is force divided by mass) during the unloading phase of the countermovement, allowing for an increased concentric phase time. This enhancement in unweighting would require improved leg muscle relaxation to permit greater downward countermovement force. Perhaps, the shaking intervention caused a decrease in neural activity or excitement. However, we did not record electromyography of the muscles and thus cannot confirm the physiological mechanism by which the relaxation technique acted. This should be investigated in the future.

The nonresponder group decreased (not statistically significant) their unweighting impulse and force compared with the responder group, when performing the relaxation technique. However, they were still able to maintain their jump performance. Only subject S02 decreased their mean jump height compared with the first jump of the day during the relaxation technique. This decrease was minimal (1.87%) compared with the larger increases in the responder group (2.17–13.51%). All other nonresponders were still able to improve their performance compared to the first jump of the day. Interestingly, those who had the highest decrease in jump height with the relaxation technique (S06 and S09) also had the highest increase in jump height during the control condition and did not fatigue like the responder group. This suggests that there may be a specific characteristic such as fitness or ability to adapt to the stimulus from each jump, which resulted in a differing response. Observing individual results, these 2 subjects improved their unweighting and eccentric impulse naturally with each jump during the control condition, but this was attenuated by the relaxation technique. Subject S02 had similar changes, but of a smaller magnitude. However, toward the end of the relaxation technique condition, S02 improved their unweighting and eccentric phase impulse. It is possible that given practice and time, the nonresponders who were naturally able to improve performance may also benefit from the relaxation technique. Alternatively, the relaxation technique may become useful to these individuals when they begin to fatigue. The extent to which there may be a negative response to the intervention and why it occurs is unclear, and further investigation is warranted.

The evidence of muscle relaxation on performance is scarce. One study, much like the previously mentioned effects on mental and physical health, used progressive muscle relaxation to evaluate effects on swimming a 50-meter front crawl and found no change in performance (30). The aim of our approach was to investigate what may already be an effective relaxation technique observed in elite athletes. Our technique may be more specific to athletic performance than progressive muscle relaxation but this

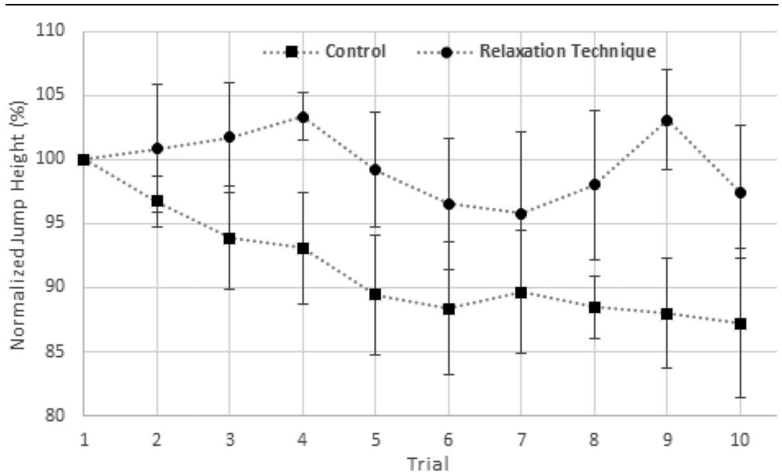

Figure 2. Mean ± *SE* of the normalized jump height for each of the 10 jumps (trials) for the responder group. During the control condition (square marker), jump height decreased relative to the first jump (100%). During the relaxation technique condition (circle marker), fatigue was mitigated.

would require future comparison. To the best of our knowledge, there is no other evidence on the effects of muscle relaxation on athletic performance. We have observed that elite mixed martial arts athletes create a sharper pulse-relaxation sequence to increase strike force when punching (17). In addition, we have observed previously in our laboratory, with volleyball players, some increased vertical jump height after a squat training program while others experienced a decreased jump height (unpublished study). Interestingly, there was a match between the volleyball players who self-identified with being either naturally quick or naturally strong. Adding more strength to the players who were neural quick, increased jump height while adding strength to those who were already strong created slowness and a loss of height. Similarly, in the current scenario, there may be an underlying neurological difference as to why some responded to the technique more than others.

The evidence provided in this study, although inconclusive on a specific biological mechanism of action, gives a foundation for future work. The within-subject comparison provides some strength of findings; however, muscle relaxation requires further investigation to determine how and to what extent it influences human movement and performance. This information can equip further exploration of the fundamental mechanism by which enhancement occurs and provide considerations for future work.

The preliminary findings presented suggests that shaking the legs with the intention to cause the muscle to relax and wobble freely improves CMJ performance by enhancing unweighting rather than enhancing propulsion, in those that fatigue with multiple bouts.

Practical Applications

Shaking the limbs as a form of voluntary muscle relaxation can improve performance by mitigating decreases in performance due to fatigue. This enhancement occurs through improvement in unweighting impulse, which requires muscle relaxation, rather than enhancing propulsive force, which is enhanced by training activation. This suggests that muscle relaxation can provide an alternate means of performance enhancement, when fatigue causes decreases in propulsion mechanisms. This technique can be used to enhance performance between multiple bouts or before performing a bout when fatigued, during training and competition.

References

1. Buccolieri A, Avanzino L, Marinelli L, et al. Muscle relaxation is impaired in dystonia: A reaction time study. *Mov Disord* 19: 681–687, 2004.
2. Chae J, Quinn A, El-Hayek K, et al. Delay in initiation and termination of tibialis anterior contraction in lower-limb hemiparesis: Relationship to lower-limb motor impairment and mobility. *Arch Phys Med Rehabil* 87: 1230–1234, 2006.
3. Chen WC, Chu H, Lu RB, et al. Efficacy of progressive muscle relaxation training in reducing anxiety in patients with acute schizophrenia. *J Clin Nurs* 18: 2187–2196, 2009.
4. Conrad A, Roth WT. Muscle relaxation therapy for anxiety disorders: It works but how? *J Anx Dis* 21: 243–264, 2007.
5. Corcos DM, Chen CM, Quinn NP, McAuley J, Rothwell JC. Strength in Parkinson's disease: Relationship to rate of force generation and clinical status. *Ann Neurology* 39: 79–88, 1996.
6. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 1—Biological basis of maximal power production. *Sports Med* 41: 17–38, 2011.
7. García-López D, De Paz JA, Jiménez-Jiménez R, et al. Early explosive force reduction associated with exercise-induced muscle damage. *J Physiol Biochem* 62: 163–169, 2006.
8. Gathercole R, Sporer B, Stellingwerff T. Countermovement jump performance with increased training loads in elite female rugby athletes. *Int J Sports Med* 36: 722–728, 2015.
9. Grasso M, Mazzini L, Schieppati M. Muscle relaxation in Parkinson's disease: A reaction time study. *Mov Disord* 11: 411–420, 1996.
10. Häkkinen K, Alen M, Komi PV. Changes in isometric force-and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol* 125: 573–585, 1985.
11. Häkkinen K, Komi PV, Alen M. Effect of explosive type strength training on isometric force-and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. *Acta Physiol* 125: 587–600, 1985.
12. Isa MR, Moy FM, Razack AHA, Zainuddin ZM, Zainal NZ. Impact of applied progressive deep muscle relaxation training on the health related quality of life among prostate cancer patients—A quasi experimental trial. *Prev Medicine* 57: S37–S40, 2013.
13. Jordan N, Sagar HJ, Cooper JA. A component analysis of the generation and release of isometric force in Parkinson's disease. *J Neurol Neurosurg Psychiatry* 55: 572–576, 1992.
14. Kim KJ, Na YK, Hong HS. Effects of progressive muscle relaxation therapy in colorectal cancer patients. *West J Nurs Res* 38: 959–973, 2016.
15. Kirby TJ, McBride JM, Haines TL, Dayne AM. Relative net vertical impulse determines jumping performance. *J Appl Biomech* 27: 207–214, 2011.
16. Matveyev L. Ways of perfecting some functional properties and complex abilities influencing movement control. In: *Fundamentals of Sports Training*. Moscow, Russia: Progress Publishers, 1981. pp. 152–165.
17. McGill SM, Chaimberg J, Frost D, Fenwick C. The double peak: How elite MMA fighters develop speed and strike force. *J Strength Cond Res* 24: 348–357, 2010.
18. McGill SM. Final transitional training - Ultimate performance with techniques of Super Stiffness and other tricks. In: 6th, ed. *Ultimate Back Fitness and Performance*. Waterloo, Canada: Backfitpro Inc, 2017. pp. 279–290.
19. McMahon JJ, Murphy S, Rej SJ, Comfort P. Countermovement-jump-phase characteristics of senior and academy rugby league players. *Int J Sports Physiol Perform* 12: 803–811, 2017.
20. Moir GL. Three different methods of calculating vertical jump height from force platform data in men and women. *Meas Phys Edu Exerc Sci* 12: 207–218, 2008.
21. Nowak DA, Grefkes C, Dafotakis M, et al. Dexterity is impaired at both hands following unilateral subcortical middle cerebral artery stroke. *Eur J Neurosci* 25: 3173–3184, 2007.
22. Robichaud JA, Pfann KD, Vaillancourt DE, Comella CL, Corcos DM. Force control and disease severity in Parkinson's disease. *Mov Disord* 20: 441–450, 2005.
23. Rodacki AL, Fowler NE, Bennett SJ. Vertical jump coordination: Fatigue effects. *Med Sci Sports Exerc* 34: 105–116, 2002.
24. Schröder A, Heider J, Zaby A, Göllner R. Cognitive behavioral therapy versus progressive muscle relaxation training for multiple somatoform symptoms: Results of a randomized controlled trial. *Cogn Therapy Res* 37: 296–306, 2013.
25. Seo NJ, Fischer HW, Bogey RA, Rymer WZ, Kamper DG. Effect of a serotonin antagonist on delay in grip muscle relaxation for persons with chronic hemiparetic stroke. *Clin Neurophysiol* 122: 796–802, 2011.
26. Sole CJ, Mizuguchi S, Sato K, Moir GL, Stone MH. Phase characteristics of the countermovement jump force-time curve: A comparison of athletes by jumping ability. *J Strength Cond Res* 32: 1155–1165, 2018.
27. Toumi H, Poumarat G, Best TM, et al. Fatigue and muscle–tendon stiffness after stretch–shortening cycle and isometric exercise. *Appl Physiol Nutr Metab* 31: 565–572, 2006.
28. Twist C, Waldron M, Highton J, Burt D, Daniels M. Neuromuscular, biochemical and perceptual post-match fatigue in professional rugby league forwards and backs. *J Sports Sci* 30: 359–367, 2012.
29. Watkins CM, Barillas SR, Wong MA, et al. Determination of vertical jump as a measure of neuromuscular readiness and fatigue. *J Strength Cond Res* 31: 3305–3310, 2017.
30. Whdan N. Effects of relaxation training on muscle tension and the performance level of 50m front crawl swimming. *Ovidius Univ Ann Ser Phys Edu Sport* 14: 143–148, 2014.
31. Yazawa S, Ikeda A, Kaji R, et al. Abnormal cortical processing of voluntary muscle relaxation in patients with focal hand dystonia studied by movement-related potentials. *Brain* 122: 1357–1366, 1999.
32. Zhou K, Li X, Li J, et al. A clinical randomized controlled trial of music therapy and progressive muscle relaxation training in female breast cancer patients after radical mastectomy: Results on depression, anxiety and length of hospital stay. *Eur J Oncol Nurs* 19: 54–59, 2015.