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Research Article

The Effects of Step versus Jump Forward Lunge as Single Exercise Training on Badminton Specific Physical Abilities

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ABSTRACT:
This study was conducted to determine and compare the effects of step versus jump forward lunge training on badminton specific physical abilities. Thirty recreationally active badminton players (mean age = 22.07 ± 1.39 years old) were recruited and divided into three groups; i) step forward lunge (SFL), jump forward lunge (JFL) and control group (CG). Lunge one repetition maximum (1RM), lunge relative 1RM, vertical jump, standing broad jump and change of direction (COD) t-test were tested pre- and post- eight weeks of training intervention. Results showed both treatment groups (SFL and JFL) had improved significantly in all tests. JFL was shown to have significantly greater improvement in lunge 1RM, lunge relative 1RM, vertical jump, and standing broad jump compared to SFL. Results demonstrated the superiority of JFL training compared to SFL in enhancing badminton specific physical abilities. However practitioners still advised to start their program with SFL and proceed to JFL after certain period of time. This is due to high contraction velocity nature of JFL which might have higher risk of injury if performed without sound strength basis.

Keywords: lunge, badminton, power, strength, speed, agility

[I] INTRODUCTION

Badminton is an intermittent sport characterized by multiple intense actions [1] including fast accelerations, decelerations and many explosive movements with changes of direction over short distances [2-5]. Badminton players need to be agile and have the ability to perform multiple lunge movement especially during the attempt to return the shuttlecock. Badminton players also need to have the ability to perform multiple jumping movements that are critical during the attempt to smash the shuttlecock. The abilities to perform these movements well will benefit the players to gain advantages over their opponents. The concept of specificity in training has received considerable mention and attention over the past decade [6]. Thus, it is important to analyse the movements been performed in a specific sport as the more similar the training activity is to the actual sport movement, the greater the likelihood of positive carryover to performance [6]. A video-based pilot study showed that lunge movement cover at least 15% of all movements, in a competitive singles games [7]. The important of lunge in a game could be seen when the player want to retrieve a drop shot where the player need to do a deep lunge to get to the shuttlecock. Athletes should accelerate quickly with the lunge to the shuttlecock because reaching the drop shot late will either result in an error or will enable the opponent to easily attack a poorly returned shot. However, having just a good acceleration is not enough as the strength to perform lunge and maintain stable to reach the shuttlecock is also needed as this will allows them to reach difficult shots, execute an effective return shot and conserve energy by executing the shot with comfortable body posture [1].

Throughout the consistency of lunge used in badminton, lunge should be widely used as training exercises during strength training program. Researches on the chronic effects of lunge were not well established. Not many researches have been conducted on determining the effects of lunge as a single training exercise [8]. Study by Bloomfield [9] found lunge training would benefit elderly women in terms of improving medial-lateral trunk stability during a lunge by decreasing peak medial-lateral trunk velocity.

Training with different protocols of lunge exercise might provide different adaptations. For example, study by Jönhagen, Halvorsen [10] have found that a six weeks period of training with walk forward lunge improved hamstring strength, whereas training with jump forward lunge improved sprint running performance. The different of adaptations could be attributed to several factors such as different in structural adaptations [11, 12] imposed by the different stimuli that was caused by the different methods of training [13-15].

Currently, lack of data exists on the effectiveness of different lunge protocols training on the badminton specific physical abilities such as lunge strength, jumping and change of direction abilities. The inclusion of lunge as training exercises should be beneficial as it will allow athletes or individuals to train and improve their ability for the movement.

As a way to overload the athletes or individuals, various methods could be implemented during training sessions [16]. This includes putting some weights and includes ballistic movement during the training. Besides that, the selection of exercise training protocols should also be based on the movements performed in the real game. In badminton, lunge is one of the preferred movements for players to reach the shuttlecock. Some players tend to reach the shuttlecock by just step in, while some players tend to jump. As these are two methods of lunge that always been performed by the players, it is aim of this study to compare the effects of step and jump forward lunge training on badminton specific physical abilities.

[II] MATERIAL & METHODS

2.1. Systematic approach to the problem

Recreational badminton players were involved as research participants in this pre- and post-experimental study. Participants were tested for badminton specific physical abilities (i.e. lunge 1RM, lunge relative 1RM, vertical jump, standing broad jump and COD t-test) before and after eight weeks of training interventions. Repeated measure multivariate analysis of variances (MANOVA) was used to determine and compare the effects of training interventions on the badminton specific physical abilities.

2.2. Participants

Thirty (30) recreational male badminton players were recruited as participants in this study (mean age: 22.07 ± 1.39 years old). Participants recruited were currently active in participating any badminton tournament, playing badminton for 3 times a week and had been actively playing for at least 1 year. In this study, participants were randomized to three groups; i) step forward lunge (SFL), ii) jump forward lunge (JFL), and iii) control (CG) groups. Participants had no medical problems and not consuming any performance enhancing supplementation. Participants were screened prior to testing using Pre-Exercise Readiness Questionnaire (PAR-Q).

2.3. Ethical Clearance

Each participant had read and signed an informed consent for testing approved by Universiti Pendidikan Sultan Idris and Thaksin

University Ethics Committee (CODE E 060/2559).

2.4. Step and jump forward lunge

Figure 1 and Figure 2 showed the step for SFL and JFL. Participants were instructed to stand while carrying a barbell with 30% 1RM loadings placed on their shoulder with their feet shoulder width apart. Participants lunged forward and must lower the thigh until parallel with the ground, and then returned back to the starting position. Participants were needed to make a big step as during downward position, the knee should not extend beyond the toe. The non-leading lower limb must not move from its starting position, and the head were constantly faced forward. As to simulate the movement used in real badminton game situation, participant bent their trunk to 45˚ forward. Jump forward lunge were performed by the JFL group. The movement was similar to the step forward lunge except participants need to explosively (jump) lunged forward and then explosively (jump) returned back to the starting position.

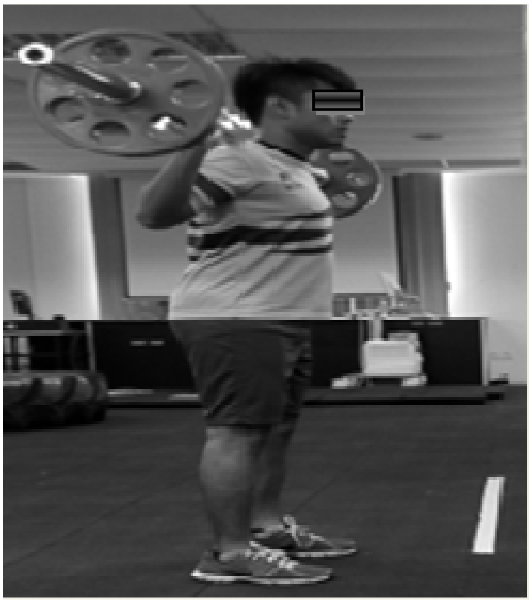

Fig. 1: Starting and Ending Phase of Lunge

Fig. 2: Middle Phase of Lunge

2.5. Multiple-RM procedure

During this study, 1RM test were not been conducted directly due to the risks that may imposed to the participants. Multiple-RM test was conducted as a way to predict 1RM value. The multiple-RM testing protocol that were conducted in this study has followed the guidelines by the National Strength and Conditioning Association (Baechle & Earle, 2008). During the test, participants were instructed to warm up with a light resistance that easily allows 5 to 10 repetitions. Next, participants were provided a 1-minute rest period. Participants were required to lift a load that he estimates can perform 8-RM with consultation with a qualified instructor. If the participants were able to lift more than 8RM, the load was increased 10% to 20% of that load based on the agreement of both participant and the tester. The load was continuously changed if the athlete can complete more than 8RM with proper exercise technique. Failure were defined as the time point when the participant paused more than 1s when the leg were in the extended position, or if the participant was unable to complete each repetition in a full range of motion [16].

2.6. Vertical Jump

A vertical jump equipment, (Vertec, USA) was used to measure vertical jump height among participants. The test started with the setting of the Vertec in which the standing height of the participant with one arm fully extended upward was taken to set the lowest vane. Participants were required to jump up and touch the highest possible vane. Participants were allowed to swing their arms and bend their knees as to simulate the real movement in sports. The jump height was measured as the difference between standing height and jumping height. Participants were given three trials and the best score was taken as the jump score.

2.7. Standing Broad Jump

Standing broad jump was used to measure horizontal jump among participants. Participants started with standing behind a line marked on the standing broad jump mat (Trident, Malaysia) with feet slightly apart. Participants were allowed to swing their arms and bend their knees to provide forward drive. Participants were asked to jump as far as possible, landing on both feet without falling backwards. Three trials were given and the best score was taken as the horizontal jump score.

2.8. COD T-Test

Four cones were set up as illustrated in Figure 2. Participants started with getting ready and stand behind the line at the cone A. On the command of the timer, the participants sprinted to cone B and touched the base of the cone with their right hand. They then turned left and shuffle sideways to cone C, and also touched its base, this time with their left hand. Participants then shuffled sideways to the right to cone D and touched the base with the right hand. They then shuffled back to cone B, touched with the left hand, and run backwards to cone A. The stopwatch (Casio HS-3V-1R, Japan) was stopped as they pass the line at the cone A.

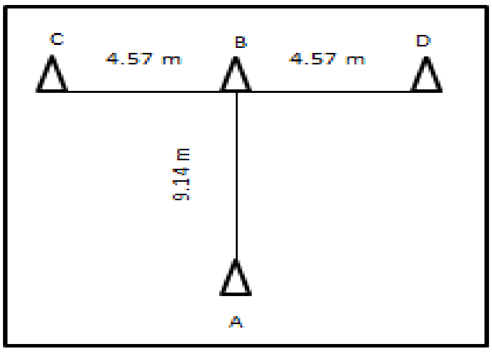

Fig. 2: COD T-Test Set Up

2.9. Data Collection

All participants involved in familiarization session in order to make sure all the participants were able to perform all the tests and training exercises correctly. After familiarization session, participants were tested for their badminton specific forward lunge one repetition maximum (1RM). The 1RM test score were used as a part of dependent variable and as determinant of training loads during this study. Participants were required to refrain from any exercise for at least 48 hours and refrain from alcohol for at least 24 hours prior to the 1RM test and experimental session. To prevent risks of injury incidence during 1RM test, multiple-RM method were implemented as it was recommended to be safer [16].

Participants involved in eight weeks of SFL or JFL training to determine and compare the effects of each training on lunge 1RM, lunge relative 1RM, vertical jump, standing broad jump and COD abilities. All the lunge technique were closely monitored and controlled throughout all sessions. Participants were required to perform the exercise to a parallel depth as determined by the femoral line (line between the greater trochanter and the lateral epicondyle) being parallel to the ground. All lunge movement were performed as fast as possible to simulate the real game situation. All the training and data collection sessions were supervised by the researcher with the assistance of appointed trained trainers. All sessions were conducted at the Physical Conditioning Lab, UPSI, Tanjong Malim.

2.10. Training Programs

Participants were divided into three groups; i) step forward lunge (SFL), ii) jump forward lunge (JFL) and iii) control group (CG). Both the SFL and JFL were required to perform the lunge training with 30% of their 1RM lunge value that were obtained during the pre-test. The intensity (30% 1RM) was chosen because this intensity allowed participants to maintain the fast and explosive movement that mimics their real movement during the game. All the participants performed the training for three sessions per week for eight weeks. During each session, participants need to perform six sets consisting of 20 repetitions per set (10 for each side of lower limb). The control groups do not involved in any resistance training program, but just continued with their daily lifestyle.

2.11. Statistical Analysis

Descriptive statistics were used to measure the mean and standard deviation of each physical characteristics and data scores. Repeated measures MANOVA were used to examine differences in lunge 1RM, lunge relative 1RM, vertical jump, standing broad jump and COD t-test in the pre- and post-training intervention within groups and the percentages changes between groups. Statistical significance were accepted at an α-level of $p \leq 0.05$. All statistical analyses were conducted using SPSS version 23 (IBM, New York, USA).

[III] RESULTS

Table 1 showed the physical characteristics of participants involved in this study.

Table 1: Physical characteristics of participants

Variables	Mean ± SD
Age (years)	22.07 ± 1.39
Body Mass (kg)	70.07 ± 1.88
Body Weight (N)	687.41 ± 13.53
Height (cm)	173.13 ± 2.12
1RM (kg)	71.87 ± 2.59
Relative 1RM (1RM/BM)	1.03 ± 0.01

Table 2 showed the pre- and post-test results of the physical abilities variables investigated in this study. Analysis on each group had found significant main effects among step forward lunge group (SFL) in all the physical performance tests thus showed that SFL group has managed to significantly improved in all tests in the post-test when compared to the pre-test: i) lunge 1RM, $F(1,9) = 801.252$; $p < 0.001$, ii) lunge relative 1RM, $F(1,9) = 239.466$; $p < 0.001$, iii) vertical jump, $F(1,9) = 2601.000$; $p < 0.001$, iv) standing broad jump, $F(1,9) = 686.270$; $p < 0.001$ and COD, $F(1,9) = 627.544$; $p < 0.001$.

Similar to the SFL group, significant main effects were also found in all the physical ability tests among jump forward lunge group (JFL) group thus showed that JFL has also improved in all tests: i) lunge 1RM, $F(1,9) = 811.234$; $p < 0.001$, ii) lunge relative 1RM, $F(1,9) = 210.617$; $p < 0.001$, iii) vertical jump, $F(1,9) = 2036.172$; $p < 0.001$, iv) standing broad jump, $F(1,9) = 268.403$; $p < 0.001$ and COD, $F(1,9) = 155.528$; $p < 0.001$.

No significant main effects were found for the control group (CG) thus showed no difference of performance between post-test and pre-test: i) lunge 1RM, $F(1,9) = 1.405$; $p > 0.05$, ii) lunge relative 1RM, $F(1,9) = 1.997$; $p > 0.05$, iii) vertical jump, $F(1,9) = 5.548$; $p > 0.05$, iv) standing broad jump, $F(1,9) = 5.129$; $p > 0.05$ and COD, $F(1,9) = 3.323$; $p > 0.05$.

Pairwise comparison showed JFL had significantly greater improvement in lunge 1RM ($p < 0.001$), lunge relative 1RM ($p < 0.001$), vertical jump ($p < 0.001$), and standing broad jump ($p < 0.05$) compared to SFL.

Table 2: Pre- and post-test results of the physical abilities tests

		SFL	JFL	CG
Lunge 1RM (kg)	Pre-test	69.24 ± 4.11	69.10 ± 4.35	69.53 ± 4.23
	Post-test	79.94 ± 3.76*	83.55 ± 3.00*	69.24 ± 4.84
	% Differences	15.54 ± 2.25[bc]	21.10 ± 3.39[ac]	-0.46 ± 1.16[ab]
Lunge 1RM (relative)	Pre-test	0.99 ± 0.02	0.99 ± 0.02	0.99 ± 0.02
	Post-test	1.11 ± 0.02*	1.16 ± 0.02*	0.99 ± 0.03
	% Differences	12.56 ± 2.74[bc]	18.00 ± 4.19[ac]	-0.45 ± 1.01[ab]
Vertical jump (cm)	Pre-test	45.90 ± 1.45	45.70 ± 1.49	46.00 ± 1.25
	Post-test	52.70 ± 1.25*	53.80 ± 1.81*	44.50 ± 3.14
	% Differences	14.84 ± 1.23[bc]	17.73 ± 1.12[ac]	-3.35 ± 4.50[ab]
Standing broad jump (cm)	Pre-test	2.53 ± 0.05	2.53 ± 0.05	2.53 ± 0.05
	Post-test	2.70 ± 0.07*	2.71 ± 0.06*	2.49 ± 0.10
	% Differences	6.55 ± 1.21[bc]	7.27 ± 0.79[ac]	-1.57 ± 2.19[ab]
COD t-test (s)	Pre-test	10.59 ± 0.24	10.59 ± 0.22	10.53 ± 0.27
	Post-test	9.70 ± 0.29*	9.59 ± 0.21*	10.63 ± 0.34
	% Differences	-8.41 ± 1.13[c]	-9.40 ± 2.25[c]	0.96 ± 1.68[ab]

[a] = significantly different from SFL [b] = significantly different form JFL
[c] = significantly different from CG * = significantly different from pre-test

[IV] DICUSSION

In this study, participants underwent eight weeks of different protocols of lunge training. Participants were divided into three groups; i) step forward lunge (SFL), ii) jump forward lunge (JFL) and iii) control group (CG).

Lunge multiple repetition maximum (RM) test was conducted before and after eight weeks of training as a predictor of lunge 1RM. The lunge 1RM was also calculated relatively to participants' body mass. Results showed that both treatment groups (SFL and JFL) had significantly improved their lunge 1RM and relative 1RM in the post-test compared to the pre-test. Both SFL and JFL was shown to have greater lunge 1RM and relative 1RM compared to control group in the post-test while JFL had significantly greater improvement in both variables compared to SFL. Results demonstrated that both SFL and JFL were effective in improving lunge 1RM and relative 1RM. JFL was shown to have greater changes of performance compared to SFL.

Findings of this study demonstrated the effectiveness of using just 30% 1RM in improving strength. This findings was in line with several studies that have found dynamic explosive training with low loads is generally considered to be useful for improving rate of force development [17-19]. Greater changes of strength showed by JFL can be suggested due to higher velocity of contraction produced by the movement. Force output is directly influence by velocity of movement [20], and with this, it may be possible that during each training session, greater stimulus was produced during JFL movement. Greater stimulus, with appropriate recovery will mean greater adaptation. Hence, greater change of strength compared to SFL.

Vertical jump (VJ) and standing broad jump (SBJ) were conducted as jumping performance assessment and were compared between pre and post and between groups in this study. Results showed that both jump assessments were improved in the post test among the treatment groups (SFL and JFL). Both SFL and JFL were effective in improving jump performance. JFL was shown to be more effective compared to SFL in improving both jump performance.

The results can be related to the principle of specificity in which training as similar as the assessments will provide more positive adaptations to the movement [16, 21]. JFL require participants to train lunge by jumping in the descent and ascent phase. The training performed by JFL group enhances the body adaptations in a specific fashion to the specific demands (i.e. jumping assessment) that are placed on it. Following training, both training groups in both studies managed to improved vertical jump height and standing broad jump distance. Although SFL group did not perform any jumping training, it was found that by just perform a movement as fast as possible is enough to improve jumping performance. The changes still occur as during training, participants were placed under some form of stress, and have challenged the muscles to produce more force. These as been trained for eight weeks improved the force production ability of the lower body muscles, thus increase their jumping abilities.

This current study showed lunge training loads of 30% of the 1RM performed by step or jumping explosively do benefit in improving jump performance. The finding is in line with several previous studies, thus showing that various intensities are beneficial in enhancing muscle power. For example, several previous studies have shown peak power or rate of force development after resistance training have been demonstrated using light (30%–40% 1RM) [22, 23], moderate (50%–60% 1RM) [24-27], heavy (70%–90% 1RM) [23, 28, 29], and even maximal loads [22, 27],43). The improvement of both vertical and standing broad jump could be related to the improvement in lunge strength. As power is the product of strength and speed, the improvement in strength among participants do contribute to better power production among participants that were reflected by better jumping performances in this study.

COD t-test was conducted as COD performance assessment and was compared between pre and post training and between groups in this study.

Results showed that both treatment groups (SFL and JFL) had significantly improved their COD performance in the post test and had greater COD t-test performance compared to control group. No significant different of improvement percentage between JFL and SFL. Results in this study demonstrated that both SFL and JFL were effective in improving COD performance. Unlike strength and jump assessments, JFL was shown not to be more effective than SFL in improving COD performance.

Lack of studies has been conducted on the effects of lunges exercise training on the COD ability. The approach used in this study (low load, high volume training programs) was shown to be effective on improving COD ability as been shown in several previous studies conducted on 40 m sprint performance [30, 31]. However, JFL in this study did not produce better improvement in COD compared to SFL, thus was in contrast to what has been found by Jönhagen, Halvorsen [10] that found JFL training to improve sprint running performance.

Looking at the results of current study, the improvement of COD time among all training groups can also be related to the improvement of the muscular strength among them. As participants have more muscle strength, the ability to produce greater speed also increased among participants.

[V] CONCLUSIONS

Overall, results demonstrated the superiority of JFL compared to step forward lunge in enhancing badminton specific physical abilities. Findings of this study provide knowledge on the effectiveness of overloading training for the movement. From periodized training point of view, although JFL has been shown to have greater improvement after training, JFL is suggested not to be used at the early stage of a training program. Strengthening with lower or normal movement velocity prior fast velocity loading of muscle, tendon and ligament should always be the practice. Thus, SFL can be used during the foundational phases and JFL during specific adaptation or competitive phase of training.

REFERENCES

1. Sturgess, S. and R.U. Newton, *Design and implementation of a specific strength program for badminton.* Strength & Conditioning Journal, 2008. **30**(3): p. 33-41.
2. Baker, D., *Improving vertical jump performance through general, special, and specific strength training: A brief review.* The Journal of Strength & Conditioning Research, 1996. **10**(2): p. 131-136.
3. Chin, M., et al., *Physiological profiles and sport specific fitness of Asian elite squash players.* British Journal of Sports Medicine, 1995. **29**(3): p. 158-164.
4. Chin, M., et al., *Sport specific fitness testing of elite badminton players.* British Journal of Sports Medicine, 1995. **29**(3): p. 153-157.
5. Hughes, M. and G. Bopf, *Relationships between performance in jump tests and speed tests in elite Badminton players.* Journal of Sports Sciences, 2005. **23**: p. 194-195.
6. Fleck, S.J. and W. Kraemer, *Designing Resistance Training Programs, 4E*2014: Human Kinetics.
7. Farrokhi, S., et al., *Trunk position influences the kinematics, kinetics, and muscle activity of the lead lower extremity during the forward lunge exercise.* Journal of Orthopaedic & Sports Physical Therapy, 2008. **38**(7): p. 403-409.
8. Nadzalan, A.M., et al., *The effects of step versus jump forward lunge exercise training on muscle architecture among recreational badminton players.* World Applied Sciences Journal, 2017. **35**(8): p. 1581-1587.
9. Bloomfield, L., *Effects of Forward Lunge Training on Balance Control in Elderly Women.* 2009.
10. Jönhagen, S., K. Halvorsen, and D.L. Benoit, *Muscle activation and length changes during two lunge exercises: implications for rehabilitation.* Scandinavian Journal of Medicine & Science in Sports, 2009. **19**(4): p. 561-568.

11. Earp, J.E., et al., *Lower-body muscle structure and its role in jump performance during squat, countermovement, and depth drop jumps.* The Journal of Strength & Conditioning Research, 2010. **24**(3): p. 722-729.
12. Nadzalan, A.M., et al., *Relationship between lower body muscle architecture and lunges performance.* Journal of Sports Science and Physical Education, Malaysia, 2016. **5**(2): p. 15-23.
13. Nadzalan, A.M., et al., *Muscle activation analysis of step and jump forward lunge among badminton players.* Journal of Engineering and Science Research, 2017. **1**(2): p. 60-65.
14. Nadzalan, A.M., et al., *Fascicle behaviour analysis during forward lunge exercise: the comparisons between training loads.* Journal of Fundamental and Applied Science, 2017. **9**(6S): p. 1090-1101.
15. Nadzalan, A.M., et al., *Kinetics analysis of step and jump forward lunge among badminton players.* Journal of Fundamental and Applied Science, 2017. **9**(6S): p. 1011-1023.
16. Baechle, T.R. and R.W. Earle, *Essentials of strength training and conditioning*. Vol. 7. 2008: Human kinetics Champaign, IL.
17. Duchateau, J. and K. Hainaut, *Isometric or dynamic training: differential effects on mechanical properties of a human muscle.* Journal of Applied Physiology, 1984. **56**(2): p. 296-301.
18. Stone, M.H., et al., *Maximum strength-power-performance relationships in collegiate throwers.* The Journal of Strength & Conditioning Research, 2003. **17**(4): p. 739-745.
19. Young, W.B. and G.E. Bilby, *The effect of voluntary effort to influence speed of contraction on strength, muscular power, and hypertrophy development.* The Journal of Strength & Conditioning Research, 1993. **7**(3): p. 172-178.
20. Cormie, P., et al., *Optimal loading for maximal power output during lower-body resistance exercises.* Medicine and Science in Sports and Exercise, 2007. **39**(2): p. 340.
21. de Villarreal, E.S., et al., *Enhancing sprint and strength performance: Combined versus maximal power, traditional heavy-resistance and plyometric training.* Journal of Science and Medicine in Sport, 2013. **16**(2): p. 146-150.
22. Kaneko, M., et al., *Training effect of different loads on the force-velocity relationship and mechanical power output in human muscle.* Scand J Sports Sci, 1983. **5**(2): p. 50-55.
23. Moss, B., et al., *Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships.* European Journal of Applied Physiology and Occupational Physiology, 1997. **75**(3): p. 193-199.
24. Häkkinen, K., et al., *Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people.* Journal of Applied Physiology, 1998. **84**(4): p. 1341-1349.
25. Häkkinen, K., et al., *Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people.* European Journal of Applied Physiology, 2000. **83**(1): p. 51-62.
26. Häkkinen, K., et al., *Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women.* Journal of Applied Physiology, 2001. **91**(2): p. 569-580.
27. Behm, D.G. and D.G. Sale, *Intended rather than actual movement velocity determines velocity-specific training response.* Journal of Applied Physiology, 1993. **74**: p. 359-359.
28. Earles, D.R., J.O. Judge, and O.T. Gunnarsson, *Velocity training induces power-specific adaptations in highly functioning older adults.* Archives of Physical Medicine and Rehabilitation, 2001. **82**(7): p. 872-878.
29. Fielding, R., et al., *High velocity power training increases skeletal muscle strength*

and power in community-dwelling older women. J Am Geriatr Soc, 2002. **50**: p. 655-662.

30. Chelly, M.S., et al., *Effects of in-season short-term plyometric training program on leg power, jump-and sprint performance of soccer players.* The Journal of Strength & Conditioning Research, 2010. **24**(10): p. 2670-2676.
31. Chimera, N.J., et al., *Effects of plyometric training on muscle-activation strategies and performance in female athletes.* Journal of Athletic Training, 2004. **39**(1): p. 24.