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Effectiveness of Muscular Power Performance on Long-Term Training

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Abstract: ***Muscular power are commonly used for increasing power in muscles and caused shortening thorough muscle but there is no strong consensus regarding how to set-up Muscular power programs to optimum effect. Here is a review of the long-term training studies to help clarify what we know. The use of plyometrics to improve muscular power outputs, even though the original use of the term was primarily to improve jumping performance. For maximizing muscular power during conventional (heavy-load) resistance-training, it seems best to train with a range of relative loads, to emphasize the relative load most relevant to the sport being trained for, to use faster repetition speeds, to use long rest periods, and to train closer to muscular failure (subject to the ability to recover from workouts appropriately).***

Keywords: muscular power, Plyometric, jumping, resistance-training

1. Can Plyometrics Improve Power?

Developing strength and muscle mass are key for athletic development. However, muscular power is thought to be even more important. Plyometrics are commonly used for increasing muscular power but there is no strong consensus regarding how to set-up plyometrics programs to optimum effect. Here is a review of the long-term training studies to help clarify what we know.

2. What is Muscular Power?

In biomechanics literature, muscular power is often discussed without clearly defining the exact terms, particularly where compound movements are being investigated. Strictly speaking, if we want to explore the ability of a given muscle to produce power, then short of doing some musculoskeletal modeling, we will need to calculate power as the product of joint moment and angular velocity. This can very easily be done in single-joint or isolation movements such as knee extensions or biceps curls and the output is a measure of joint power, which involves all of the muscles acting on the joint. However, when exploring compound movements, things become more complicated, as we will see later on. Nevertheless, irrespective of whether we are investigating isolation or compound movements, if we are going to understand power, then we need to understand how changing either force (or joint moment) or velocity (or angular velocity) affects the other. We can do this most easily by looking at the force-velocity relationship.

3. What is the Force-Velocity Relationship?

Individual muscles are thought to follow a fairly predictable force-velocity relationship, which is negative and hyperbolic. Being negative means that the greater the external load, the lower the contraction velocity. Similarly, the higher the contraction velocity, the lower the internal muscle tension. Being hyperbolic means that the rate of change of force alters with changing velocity. At low velocities, the rate of change of force is very high and it drops off quickly with small increments in speed. At higher velocities, the rate of change of force is quite low and alters little with each incremental change in speed. The force-velocity relationship was originally described by (Hill, 1938) and his formula includes two constants as well as maximum isometric force. The following diagram presents this force-velocity relationship and its consequences for muscular power.

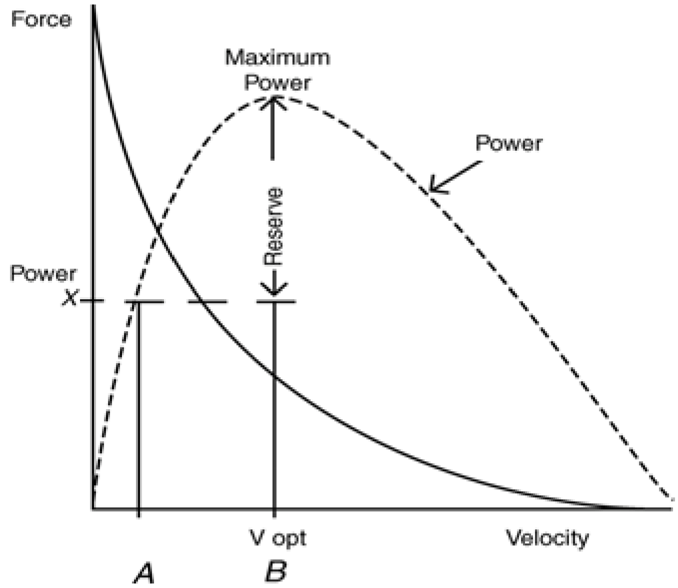

Figure 1: Schematic illustration of force–velocity relationship of muscle, as shown by the continuous line

The diagram shows that while force decreases rapidly as velocity increases, the product of force and velocity (i.e. power) is greatest when both force and velocity are moderate values rather than when either force or velocity is very high. Thus, we can deduce that power outputs are most likely to be greatest when moderate loads and moderate velocities are used.

4. Why not Just Measure Jumping Height?

Many older studies simply measure jumping height and refer to this as a measure of muscular power. However, later research made it clear that this simplistic approach is not valid, for two key reasons, as follows: Anthropometric characteristics affect jumping height and/or its relation with power output, including body fat percentage (Kerns, 2013), body mass (Markovic, 2014) and even ethnicity (Rouls, 2014). Therefore, individuals with different anthropometric characteristics may jump to different heights than others, even if power outputs are similar. Motor learning seems to have a very large effect on vertical jump performance, as trained individuals display very close correlations between power output and jump height, while untrained individuals do not (Tessier, 2013). Thus, assessing vertical jump height as a proxy for power output may become more valid as the level of expertise displayed by the athlete in jumping increases. For these reasons, is not valid to use vertical jump height (either squat jump or countermovement jump) as a measure of muscular power in all populations, although they are perfectly good measures of sporting performance. It all depends on what you are trying to measure.

5. What are Plyometrics?

The term "plyometrics" was first popularized with the Soviet jumping coach, Verkoshansky. He wanted to explore ways to develop the jumping ability of athletes who had already attained significant gains using standard methods at the time, which comprised jumping practice and resistance-training. Verkoshansky reasoned that since there seemed to be a correlation between short ground contact times and better performances in triple jumpers, this could imply that a greater stiffness (or a superior ability to store and release elastic energy) could be the key to improved jumping ability. Thus, he started using depth jumps with his athletes in order to increase their ability to switch from eccentric muscle actions to concentric muscle actions more quickly; thereby reducing ground contact times (Faccioni, 2001).

While many coaches still think of plyometrics in these terms, the usage in the modern literature has changed substantially. Today, the term plyometrics refers to explosive, compound upper- or lower-body movements involving the stretch-shortening cycle (Marcovic, 2010). For the lower-body, various different types of jumps are included within this definition and for the upper-body, medicine ball throws are a frequent example. There is therefore a difference between the earliest popular usage of the term by Verkoshansky and his later disciples and the modern sports science literature, which seems to use the term as a subset of ballistic resistance-training exercises, being those using very low-loads or no-load and which involve the stretch-shortening cycle. Moreover, it is often stated that such plyometrics are the key to bridging the qualities of strength and power (McNeely, 2005). Thus, there is also a difference between the intended purpose of plyometrics between the early popular usage and usage in modern sports science, as Verkoshansky intended the training modality to improve jumping performance, while modern literature expressly refers to increases in muscular power. If Verkoshanksy was correct and the means by which plyometrics improves jumping performance is by increasing stiffness, then we might not necessarily see substantial changes in power, or at least we might see smaller changes than by other training modalities.

6. What were the Selection Criteria?

The following studies assessed the effects of plyometrics on muscular power during long-term experimental trials, where the outcome measure was a measurement of muscular power expressed in Watts. Studies that were included had to only involve plyometrics and not carry out plyometrics in combination with other training modalities.

7. Can Plyometrics Improve Power Output?

The following studies assessed the effects of plyometrics training programs on muscular power output and are summarized in the table below:

Table 1: Assessed the effects of plyometrics training programs on muscular power output

Study	*Significant?*	*Non-significant?*	*Training status?*	*Program duration?*
Chelly (2014)	Yes	n/a	Trained adolescents	8 weeks
Chaouachi (2014)	Yes	n/a	Untrained children	12 weeks
Markovic (2007)	Yes	n/a	Untrained	8 weeks
Chelly (2010)	Yes	n/a	Trained adolescents	8 weeks
Vissing (2008)	Yes	n/a	Untrained	12 weeks
Ronnestad (2008)	Yes	n/a	Trained	7 weeks
Canavan (2004)	Yes	n/a	Untrained	6 weeks
Luebbers (2003)	Yes	n/a	Untrained	4 and 7 weeks
Diallo (2001)	Yes	n/a	Trained adolescents	10 weeks
Fatouros (2000)	Yes	n/a	Untrained	12 weeks
Potteiger (1999)	Yes	n/a	Untrained	8 weeks
Wagner (1997)	Yes	n/a	Trained and untrained	6 weeks
Hewett (1996)	Yes	n/a	Trained	6 weeks
Holcomb (1996)	Yes	n/a	Untrained	8 weeks
De Villarreal (2012)	No	Yes	Untrained	7 weeks
Saunders (2006)	No	Yes	Trained endurance athletics	9 weeks
MacDonald (2013)	No	Yes	Lightly trained	6 weeks
Marcovic (2013)	No	Yes	Untrained	10 weeks
Wilson (1993)	No	No	Trained	10 weeks

Chelly (2014) assessed the effects of an 8-week biweekly program of plyometric training in addition to the normal in-season training of 23 top-level adolescent handball players on squat and countermovement average power output and estimates of leg muscle volume. The subjects were assigned either to a control group or to an experimental group. The researchers found that the plyometric training group improved countermovement jump power as well as leg muscle volumes relative to the control group.

Chaouachi (2014) compared the effectiveness of plyometrics and conventional (heavy-load) resistance-training programs in 63 children (aged 10 – 12 years) over a 12-week training period. Before and after training, isokinetic power was measured at both 60 and 300 degrees/s. The researchers found that plyometrics were superior to conventional (heavy-load) resistance-training for isokinetic power at 300 degrees/s while conventional (heavy-load) resistance-training was superior to plyometrics for isokinetic power at 60 degrees/s.

MacDonald (2013) compared the effectiveness of plyometrics and conventional (heavy-load) resistance-training programs in 34 recreationally-trained, college-aged males by reference to counter-movement jump peak power output. The researchers did not detect any effect of the training programs on counter-movement jump peak power, nor did they find any differences between groups.

Marcovic (2013) compared the effects of vertical jump training and weighted vertical jump training on muscular power output during the squat and countermovement jumps in physically active but untrained males over an 8-week period. The weighted vertical jump condition used a weighted vest equal to 30% of body weight. The researchers found that the training period led to similar increases in power in the squat jump (7.4 – 11.5 %) but there were differences between groups in respect of the countermovement jump (0.5 vs. 9.5%), whereby the weighted vest group displayed superior results in power output.

De Villarreal (2012) compared the effects of plyometrics and heavy-load resistance training in 65 physical education students (47 males and 18 females). The heavy-load resistance training group trained using the full-squat exercise with 56 – 85% of 1RM for 3 – 6 repetitions and the plyometrics group performed jumping. The improvement in power output in the plyometrics group was non-significant.

Chelly (2010) assessed the effects of an 8-week lower limb plyometric training program (hurdle and depth jumping) in combination with normal in-season conditioning on peak power output during countermovement jumps in 23 junior soccer players. The subjects either performed normal conditioning or normal conditioning plus bi-weekly plyometric training. The researchers also measured leg muscle volume. They found an increase in the plyometrics group relative to the standard group in relation to average power and thigh muscle volume.

Vissing (2008) compared the effects of conventional (heavy-load) resistance-training with plyometrics of equal time and effort in 15 young, untrained males over a 12-week period. The researchers found that plyometrics led to significant increases in power output during the countermovement jump (9%) and ballistic leg press (17%). The researchers also noted that quadriceps, hamstring, and adductor whole-muscle cross-sectional area increased equally with both types of training.

Ronnestad (2008) assessed the effects of plyometric training on power output in 14 professional soccer players over a 7-week intervention. The subjects were randomly divided into 2 groups. One group performed a plyometric training program twice a week as well as 6 – 8 soccer sessions per week. A control group just performed 6 – 8 soccer sessions per week. The researchers measured peak power in the half squat with 20, 35, and 50kg before and after the intervention. The researchers found that the training group significantly improved peak power in the half squat with 20, 35, and 50 kg but the control group only improved peak power with 20kg.

Markovic (2007) compared the effects of sprint training with plyometric training on muscular power outputs in 93 male physical education students. Power output was measured during the squat and countermovement jump. The training groups trained 3 days a week. The sprint group performed maximal sprints over distances of 10 – 50m and the plyometric performed bounce-type hurdle jumps and drop jumps. The researchers found that the sprint group significantly improved squat and countermovement power (4% and 7%) whereas plyometric training did not.

Saunders (2006) assessed the effects of including plyometrics in the training programs of 15 highly trained distance runners. The plyometrics training involved 3 x 30 minute sessions per week for 9 weeks. The researchers found that average power during a 5-jump plyometric test increased non-significantly in the plyometrics group (15%) compared to the control group.

Canavan (2004) compared the measurement of actual peak power during a countermovement jump with calculations derived from three different prediction equations following 6 weeks of plyometric training in 20 college-age females. The researchers found that peak power increased significantly following training.

Luebbers (2003) compared the effects of two different plyometrics programs with similar training volumes on vertical jump performance and power output in 38 physically active, college-aged men. The groups performed the same amount of training but one group performed it over a 4-week period and the other over a 7-week period. Vertical jump power increased significantly in both groups with no significant differences between the groups. There was a non-significant trend towards a greater increase in the 7-week group, whose training frequency was lower.

Diallo (2001) explored the effectiveness of plyometrics in 20 prepubescent soccer players, aged 12 – 13 years over a 10-week period. The plyometrics comprised jumping, hurdling and skipping. The researchers found that peak power increased significantly following training.

Fatouros (2000) compared the effects plyometrics, heavy-load resistance-training, and their combination in 41 men over a 12-week intervention. The subjects trained 3 days per week. The researchers found that peak power increased significantly following training.

Potteiger (1999) compared the effects of plyometric-only and plyometric + aerobic training on power output over an 8-week intervention with 19 male subjects. The plyometric training consisted of vertical jumping, bounding, and depth jumping. The aerobic exercise was performed at 70% of maximum heart rate for 20 minutes immediately after the plyometric workouts. The researchers found that peak power output during a countermovement vertical jump increased significantly as a result of the intervention in both groups and there was no difference between groups (2.8 and 2.5%). In addition, the researchers measured a change in both type I (4.4 and 6.1%) and type II (7.8% and 6.8%) muscle fibers areas, suggesting that the increases in power output may have arisen partly from hypertrophy.

Wagner (1997) assessed the effects of 6 weeks of plyometrics on anaerobic power in 20 athletes, 20 non-athletes and 20 controls. The researchers found that plyometrics is effective for increasing lower body anaerobic power for both athletes and non-athletes.

Hewett (1996) assessed the effects of plyometrics on landing mechanics and power outputs in female athletes involved in jumping sports. After training, the researchers found that hamstring muscle power increased significantly by 44% on the dominant side and by 21% on the non-dominant side.

Holcomb (1996) assessed the effects of a modified plyometric program in 51 college-age men who performed either a conventional depth jump program, a modified depth jump program, a countermovement jump program, or a resistance-training program. The subjects trained 3 days a week for 8 weeks. The researchers found that all of the groups improved peak power output and there were no significant differences between the various training methods.

Wilson (1993) compared the effects of heavy-load resistance-training, plyometrics, and ballistic resistance-training at the load that maximized mechanical power output in 64 previously trained subjects, training twice per week for 10 weeks. The plyometrics program involved depth jumps of increasing height over the course of the intervention; from 20cm to 80cm. Power output was measured using a 6-second cycle ergometer test. Power output did not improve significantly following the plyometrics training intervention as measured in this test (0.6%). This may have been a function of the test, which does not make use of the stretch-shortening cycle, where the depth jump is thought to train this extensively.

8. How Can We Summarize These Findings?

In summary, the use of plyometrics to improve muscular power outputs seems validated by the above literature, even though the original use of the term was primarily to improve jumping performance.

Additionally, we can see from the few studies that have measured changes in muscle size at the same time as changes in power outputs that at least part of the mechanism by which plyometrics improves muscular power is through hypertrophy (e.g. Chelly, 2014; Chelly, 2010; Vissing, 2008; Potteiger, 1999). Thus, claims that plyometrics only act via neural drive and do not lead to local adaptations are not substantiated. Moreover, it is interesting that where muscle fiber type was explored (e.g. Potteiger, 1999), both type I and type II fiber areas displayed increases in size.

We can also note that where plyometrics have been carried out in combination with aerobic training (e.g. Diallo, 2001; Saunders, 2006; Ronnestad, 2008; and Chelly, 2010), this does not seem to have hindered the gains in muscular power in any way. This suggests that plyometrics can be used to increase muscular power even where aerobic exercise is simultaneously being carried out.

The study performed by Luebbers (2003) in which different training frequencies were performed is difficult to interpret. The lack of significant differences between the increases in muscular power output between the two groups that performed the same number of sessions over different periods of time seems to suggest that greater training frequencies can achieve faster adaptations.

Finally, we can see from a very limited pool of studies that no differences have been found in respect of the power gains that arise from performing different jumps, such as depth jumps vs. countermovement jumps (e.g. Holcomb, 1996). This is interesting, as Verkoshansky introduced depth jumps specifically in order to improve jumping ability in trained jumpers. Whether this implies that the mechanism by which depth jumps were particularly successful at improving jumping performance in this population was not by improving muscular power but by another mechanism is unclear from the present analysis.

9. What are the Practical Implications?

- Plyometrics can be used to increase muscular power output in trained and untrained populations and in both adults and adolescents.
- There is no good evidence for preferring any specific type of plyometrics exercise for increasing muscular power output.
- Greater training frequencies may be able to achieve faster increases in muscular power output during plyometrics training programs.
- Plyometrics can be carried out successfully in addition to programs involving aerobic training in order to increase muscular power output.
- Where increases in power output are desired without changes in muscular size, plyometrics should not be the default method, as hypertrophy is associated with this type of training.

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