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Community Review

# Literature Review: Neuromuscular Response to Plyometric Training

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## INTRODUCTION

Plyometric exercises are a training stimulus that were developed in an attempt to bridge the gap between weight room muscular strength exercises and the speed or power needed on the track, field or court. Verkhoshansky (2018) uses physics to describe his method of plyometrics where a falling body creates kinetic energy which, upon impact with the ground, causes a high degree of muscle tension. The impact stimulates high threshold motor neurons and these, along with elastic energy, create the potential for an enhanced stretch shortening cycle with minimal amortization. This modality of training is a well-established method to improve vertical jumping ability (Adams et al., and Fatourous et al., 2000), and sprinting abilities as well (Miller 1980; Chu 1983), however, there still seems to be confusion surrounding its application. With most of the early research on plyometrics coming from Russia, a lot of the early information was lost in translation which lead to misapplication in the United States (Verkhoshansky, 2018). One clear example of this is in the execution of a drop jump versus a depth jump, and the appropriate height for each of these exercises (Verkhoshansky, 2018). The depth jump was typically performed on a 75cm box, with a larger countermovement, and an end goal of jumping as high as possible, while the drop jump typically used 30-45cm, landing with stiff legs and a minimal countermovement, sought to minimize ground contact times through the usage of elastic energy, while maximizing vertical displacement (Verkhoshansky, 2018).

Researchers have shown that these exercises are capable of improving performance, but it has been hard to pinpoint the mechanism behind the adaptations. Vershoshansky (2018) indicated that when depth jumps are incorporated into a training cycle, they actually replace the heavy squat, yet at the end of the cycle his athletes' squat maxes would increase. This would indicate that improved strength and force production could be a driving force behind the improvements in running speed and jumping abilities. Looking at this explanation, investigators might need to look at the neural aspects of movement including motor unit recruitment and increased muscle activation to find the process behind adaption and improved athletic performance as well as looking at the stretch shortening cycle itself as the elastic energy minimizes the amortization phase. Verkhoshansky (1979) believed the neuromuscular system's reaction to plyometric activity to be protective in nature and a result of either utilization of the stretch reflex, elastic energy recoil, or increased CNS activation due to rapid eccentric movements. If a more precise channel for what creates the adaptation is found it may allow for better programming which would not only enhance the adaptation but could lead to a reduction in injury. Therefore, the purpose of the review of literature is not to show that this modality of exercise can enhance athletic performance but, to gain an understanding on what mechanism drives the adaptation.

## NEURAL IMPACT

Exercise is designed to place stress on the body which elicits a response and adaptations occurs. From a neuromuscular standpoint those adaptations can include both changes to motor unit recruitment, activation and inhibition of muscle fibers, changes in fiber phenotype and hypertrophy. Markovic and Mikulic (2010) note the important role the central nervous system plays in promoting muscle activity both before impact and during activity in the completion of plyometric type activities. Looking at this from a chronic perspective Chimera et al. (2004) used 21 female soccer players performing 6 weeks of off-season workouts, with the only difference being the plyometric group included two sessions of plyometric activities. Looking at a group-by-session interaction a significant increase in the preparatory phase adductor-to-abductor muscle coactivation was noted ($F_{1,15}$=5.267, P=.037), this translates to a plyometric group increase in coactivation from 48±12% to 102±46% from pre-test to post-test as opposed to a control group decrease of 64±49% to 55±29% pre-test to post-test. There was also a trend with quadriceps-to-hamstring muscle coactivation ($F_{1,16}$=4.346, P=.053). This pre-activation indicates an adaptation based on neural control which may be performance based or an injury preventative mechanism and is supported by Wu et al. (2010) who used a similar protocol of training lasting 8 weeks with 21 male athletes and looked at the soleus muscle group. While the control group had minimal change in activation from pretest (.039±.018) to mid-point (.037±.019) to post test (.040±.020), the experimental group showed significant increases from pretest to mid-point (p=.001, .031±.012 to .046±.015) and from pretest to posttest (p<.001, .031±.012 to 046±.015). Adding support to the idea of a neural mechanism being the mechanism of increased performance following plyometric training is the study by Taube et al. (2011), who looked at neuromuscular activity based on different box drop heights. Taube et al. (2011) noted that plyometrics can change muscle activation and that it is dependent upon the height of the box. When falling from a high box, the muscle activity in the soleus and rectus femoris did not change during the drop or the eccentric portion of the action, however during the concentric phase there was a significant increase in soleus activity ($F_{3,30}$=5.0; P=.007), and in rectus femoris activity ($F_{3,30}$=4.7; P=.008. ). Results from the low box also showed increased muscle activity but it occurred only during the drop and eccentric portion of the exercise and only in the soleus ($F_{3,30}$=5.1; P=.006)

The first two studies looked at basic level plyometrics while the third study investigated more intense exercises; yet all three of these studies show increased muscular activation in various muscles in response to plyometric training. Specifically, it appears that the adaptation is a neuromuscular sequence pattern used not only to enhance performance but also acts as an injury prevention mechanism. Looking at the study by Chimera et al. (2004) we saw early activation of the adductor muscle which could possibly be done to stabilize the knee joint thereby reducing the likelihood of injury. While the other two studies focused on the soleus, both indicated a similar pre-activation pattern, and while it primarily acts as a stabilizer for the ankle it also can regulate knee flexion through control of the tibia. The interesting aspect of the Taube et al (2011) study was difference in activation due to box height. As the box height increased soleus pre-activation decreased which could be attributed to increased knee and hip flexion which was needed to absorb the force from the fall. Increased stabilization of the joint could lead to improved performance as the pathway from force production to where the force will be applied becomes more direct. Performance could also be enhanced due to increased stiffness in the tendon and joint allowing for a minimized amortization phased through, a quicker absorption of elastic energy and conversion into kinetic energy.

## STRETCH SHORTENING CYCLE

The stretch shortening cycle allows for higher and quicker force production and refers to any pre-stretch or countermovement that occurs before a movement, and consists of an eccentric, amortization and concentric phase, though the countermovement is generally eccentric. The benefits can be lost if the movement time is extended due to high external forces resulting in a lower velocity concentric phase. Hirayama et al., (2017) looked at the effects that plyometrics had on the stretch shortening cycle by looking at impulse, ground contact times and reaction forces between a control group that performed regular training, and a plyometric program that consisted of squat jumps or depth jumps three days a week for 12 weeks. The plyometric group showed a significant increase in impulse (P< 0.001; Pre: 168±21 N·s, Post: 192±20 N·s) and decrease in contact time (P<.01; (Pre: 0.365±0.068 s, Post: 0.310±0.043 s) while the control group showed no change in impulse (Pre: 160±13 N·s, Post: 155±20 N·s) or contact time (Pre: 0.388±0.061 s, Post: 0.402±0.093 s). The reaction forces in the phase just prior to amortization and the phase just after amortization increased in the plyometric group (p<.01; Pre: 1205±213 N, Post: 1510±175N) and (P<.001; Pre: 1150±125N, Post: 1490±180N) respectively, while the control group had showed no change in either phase (Pre: 1111±205 N, Post: 1141±253 N) and: (Pre: 1054±152 N, Post: 1117±201 N 391±52 N [Pre], 346±67 N [Post]). Taube et al. (2011) also looked at contact times and noted adaptations were specific to the box height. Plyometric drop jumps from a lower box decreased contact times (P<.002, Pre: 195±18ms, Post: 185±12ms) whereas the higher box increased contact times (p>.05, Pre: 220±18ms, Post: 221±20ms). In these studies, ground contact time and impulse may be directly related, as impulse increases after chronic plyometric training indicating the subjects are either hitting the ground at a higher velocity or taking off at a faster rate of speed. Since the box height and subjects' mass remained constant throughout the experiment, it can be concluded that they are taking off at a faster rate of speed. If they are taking off at higher velocity most likely there is a decrease in time during the concentric portion of the exercise which would decrease ground contact times.

Hakkinen and Komi (1985) also looked at eccentric and concentric reaction forces before and after plyometric training that involved various heights of drop jumps and weights using a countermovement jump and standing jump. In contrast to Hirayama et al. (2017) Hakkinen and Komi (1985) noted no difference in eccentric reaction forces or concentric reaction forces for jumps performed at 20 or 60 cm, and only showed a change in concentric force at 100 cm (P<.05, Pre: 1218±257N Post: 1408±325N). This could indicate the utilization of elastic energy was insufficient to produce a dynamic contraction, therefore instead of a reactive type exercise this may be a strength producing exercise. When looking at countermovement jumps Hakkinen and Komi (1985) saw an increase in eccentric reaction forces in all three conditions, unweighted (P<.01, Pre: 564±191N Post: 791±141N) with 40kg (P< .01, Pre: 386±131N Post: 643±166N) and 100kgs (P<.01, Pre: 262±98N Post: 436±161N). They also noted increase in concentric reaction forces in all three conditions, unweighted (P<.001, Pre: 712±173N Post: 850±131N) with 40kg (P< .01, Pre: 574±120N Post: 681± 99N) and 100kgs (P<.01, Pre: 382±91N Post: 550±100N). The direct results from the countermovement jumps indicate unweighted jumps are more reactive in nature. They also show the importance of gravity as weighted jumps limit the vertical displacement produced which limits the velocity at which ground contact is made possibly leading to limited eccentric reaction force. Therefore, if one wanted to emphasize eccentric reaction forces unweighted jumps would be a better option then weighted jumps. Now when looking at the drop jumps performed in the Hakkinen and Komi (1985) study and comparing them directly to Taube et al. (2011) we see an increased concentric reactive force and an increased contact time when utilizing the high box. A high box results in landing at a higher velocity due to gravitational forces. This can cause a change in the kinematics as the body utilizes a larger counter movement to absorb the force, which will not only contribute to the increased contact time but also cause a longer amortization phase. A longer amortization phase causes potential energy to be lost which would then translate into a need for greater concentric forces to be applied to complete a movement.

Looking at these three studies together we see that different types of plyometric activities can cause adaptations to the stretch shortening cycle and these adaptations may be specific to the demands placed on the body. Activities that involve smaller counter movements such as unweighted jumps or drop jumps from smaller heights appear to be more reactive in nature which maybe more beneficial to stressing the eccentric component of the stretch shortening cycle and helping to minimize the amortization phase. A shorter amortization phase should lead to a greater storage of elastic energy, therefore, enhancing the rate of force development in the concentric phase. Exercises that require weight or drops from higher boxes appear to lengthen the amortization phase placing a stronger emphasis on enhancing the concentric phase of the stretch shortening cycle. While this could lead to a slower rate of force development it could increase concentric strength. Therefore, when implementing these exercises, one needs to know what goal they are trying to maximize, with short boxes and unweighted jumps seemingly being more beneficial in maximizing power in time restraint activities while weighted jumps or high box jumps can be more beneficial at increasing overall jumping height in activities not restrained by time.

## STRENGTH AND POWER

Strength and power are two variables that may be directly affected by plyometric training. Wilson et al. (1996) used 45 recreationally trained individuals with no plyometric experience to compare the effects of a strength training protocol compared to a plyometric protocol. Both groups trained two times per week, for eight weeks, with the strength group performing six sets of at least 6 but no more than 10 repetitions in the back-squat exercise and the plyometric group started with 32 jumps at 20cm and progressed to 48 jumps with 16 of them at 70cm. While both protocols initiated similar increases in vertical jumping abilities, the way they achieved the increases were different. The strength training group showed significant improvements in one repetition maximum squats (P<.05, Pre: 115±19.8 kg Post: 139±18.9 kg) with no improvement in concentric rate of force development or eccentric rate of force development. The plyometric group showed a significant improvement in eccentric rate of force development

(P<.05 Pre:12000±3440 N·s-1 Post: 15300±4830 N·s-1) with no other improvements noted. This is in contrast to the findings of Macdonald et al. (2012) who had subjects train two times a week for nine weeks, and looked at the strength gains in a squat, RDL and calf raise between a strength only group, a plyometric only group and a combination group. During the study all three groups showed a significant increase in strength in the squat, RDL and calf raise from pretest to post-test with no difference between groups. The strength only group had the following results for the squat (p=0.00 Pre: 130±30kg, , Post: 181kg±50kg), RDL (p=0.00 Pre: 97±33kg, Post: 139kg±50kg) and calf raise (p=0.00 Pre: 159±41kg, Post: 240kg±60kg) while the plyometric only group improved in the squat (p=0.00 Pre: 118±32kg, Post: 139kg±220kg), RDL (p=0.00 Pre: 90±27kg, Post: 120±20kg) and calf raise (p=0.00 Pre: 165±52kg, Post: 22kg±60kg), finally the combination group showed increases in the squat (p=0.00 Pre: 116±30kg, Post: 161kg±22kg), RDL (p=0.00 Pre: 100±22kg, Post: 131±30kg) and calf raise (p=0.00 Pre: 175±25kg, Post: 260kg±60kg). Saez de Villarreal et al., (2013) results were consistent with this except showing both a squat only group and plyometric only group could significantly increase squat strength (P<.01), however, they showed significantly larger (P<.05) strength gains in the squat only group; squat group increase (P<.05, 17.4kg, ES=.85) plyometric group increase (P<.05, 5.91kg, ES=.48). These two studies show a possible link to strength improvement through the use of plyometric activities, in fact Verkhoshansky (2018) noted. However, Wu et al. (2010) showed increased neural activity in the soleus and Taube et al. (2011) showed increased activity in the soleus and rectus femoris during different stages of landing and take-off following plyometric activity. This could indicate the strength increases resulting from plyometrics have a strong neural mechanism.

Looking at these three studies, it appears that strength can be an important factor for improving a power type movement such as a vertical jump, however, it remains uncertain as to whether plyometrics can directly increase strength. The Saez de Villarreal et al (2013), makes no mention of the plyometric protocol used, if we look at Wilson et al. (1996), they only used depth jumps ranging from 20-70cm while MacDonald et al. (2012) used depth jumps ranging from 30-45cm and also include box jumps, unilateral jumps and horizontal based jumps. The extra volume of plyometric work in the Mac Donald et al., (2012) study could be the reason why they saw a significant increase in leg strength. Wilson et al. (1996) did note an increased eccentric rate of force production which, if we look at Taube et al. (2011), would indicate that they spent the majority of the time using a lower box for their jumps. It is quite possible that if they had spent more time with a higher box, they would have seen less of an eccentric rate of force development increase and possibly an increase in squat max due to an increased amortization phase needed to absorb the higher forces created from a taller box.

## CONCLUSION

Currently, plyometric training is a widely used exercise modality employed to improve sprinting and jumping abilities. While this aspect of usage is strongly supported through research, the proper implementation of intensity, volume and selection of these exercises is still misguided. We have the end goal in mind, but without understanding the process that leads to it, decisions can be misguided which, not only diminishes the expected results, but also can lead to injury. Coaches who don't understand the mechanism behind adaptation may increase box heights or the weight used in jumps beyond what the body can adapt to. This can lead to faulty mechanics which not only diminishes the performance enhancement qualities but also the likelihood of injury occurring. This review has shown that different exercise selection can impact muscle activation through coactivation of antagonist muscles, pre-activation of muscles before they are needed, or even delay muscle activity during the eccentric contraction activating them as the concentric range of motion begins. By looking at ground force reactions in both eccentric and concentric actions as well as ground contact times we have seen how the stretch shortening cycle is impacted by various intensities of plyometric exercises.

Original plyometrics were designed as bilateral exercises, used to imitate the quick ground contact times and excessive forces produced during athletic activities. However, most athletic activities are unilateral in nature and while people have started to implement unilateral plyometrics for this reason, very little research has been performed on them. Current research has focused on plyometric drills performed in the sagittal plane, while some athletic activities like change of direction are done in the frontal plane. We know plyometrics when implemented properly can improve athletic ability and we are starting to realize the adaptions they cause to the neuromuscular system.

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