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Postactivation Potentiation (PAP)

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This paper was presented as part of the NSCA Hot Topic Series.

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Introduction

Postactivation Potentiation (PAP) is the phenomenon bywhich the contractile history of muscles directly affects their subsequent rate of force development (RFD) or the ability to generate force in a rapid manner. The theory behind PAP is that the acute change in contractile proteins and motor neuron activity can help induce greater explosive power performance for a 2- to 20-min period followingheavy loading (9,40, 47).

There is currently insufficient research to provide guidelines for its use as a training tool; however, researchers have examined exercises to produce and to measure the performance enhancement (potentiation), with rest periods of varied duration that allows for optimal potentiation (1,11,12,18,23,25,27,35,53).Researchers working to determine PAP's usefulness in the performance training arena usually begin with a conditioning stimulus followed by a period of rest, then an explosive power exercise (12,35,43). The use of PAP in training sessions is typically called complex training (CT) (9,5,41,7,51). Within an exercise session, an athlete using CT will perform pre-designed complexes of paired exercises (51).

The goal of this Hot Topic is to shed light on the science behind PAP for the exercise science professional, coach, and athleteand to provide ideas and suggestions forhow to implement CT.

Mechanisms

Numerous mechanisms associated with PAP have been hypothesized, including increased motor neuron activity, increased reflex electrical activity, enhanced blood flow to muscles, psychomotor enhancement, and increased myosin light chain (MLC) phosphorylation (6,8,15,17,22,30,38,39,45,51,55). The research currently points to MLC phosphorylation as one of two mechanisms by which PAP occurs (17,45,39,55). When myosin—the protein in the muscle cell responsible for muscular contraction—becomes phosphorylated, the myosin may have a more rapid rate of binding to actin, the other primary contractile protein (46). This phosphorylation occurs because of the intramuscular calcium saturation present for the duration of muscular contraction (45). The second mechanism by which PAP may occur is motor neuron enhancement causing greater recruitment of fast twitch muscle fibers (47).It is upon these mechanisms that the procedures of PAP should be applied. That is, the goal of a potentiating activity should be high-intensity contraction of sufficient duration to cause PAP to occur, and the potentiated exercise should be an explosive activity.

Athlete Training Status

Training status of an athlete using PAP is probably the single largest determinant of success in achieving measurable potentiation (12,18,27,22). Based on the mechanism discussed previously, everyone will experience enhanced MLC phosphorylation following a high-intensity conditioning stimulus, but fatigue from the same stimulus may outweigh the enhanced contractile ability in lesser-trained athletes (22,36).

It should also be expected that PAP will cause greater increases in power performance in athletes with a greater percentage of fast-twitch muscle fibers (19). Type II muscle fibers undergo greater phosphorylation, and therefore potentiation, than type I fibers (31,33). Unfortunately, obtaining the fiber-type compositions of a team of athletes to determine which athletes could effectively use PAP, or to what degree one athlete versus another would benefit, is not a reasonable endeavor.

Relative strength—the percentage of an athlete's body weight that can be lifted—has been correlated with percentage of improvement exhibited with the implementation of PAP (27). Relative strength may also be a predictor of PAP utility (21). Although no cutoff value can be given for minimum relative strength, it appears that athletes become more likely to exhibit improved performance with PAP if their relative strength approaches two times their body weight using a three-quarter squat (21). This may be due to a greater percentage of cross-sectional area (CSA) of type II muscle fibers in those with high relative strength (4,44). The recommendation is that PAP should only be implemented in resistance-trained athletes with very high relative strength.

Potentiating Exercises

Various exercises have produced PAP in well-trained athletes (11,35,43). Among these exercises, the back squat, or some variation of the back squat, and the bench press are most frequently used in attempts to induce potentiation (2,8,10,12,15 ,18,22,23,24,26,27,43,53). It appears that the exercise selection for induction of PAP is less critical than the training status of the athletes. Research indicates that the exercise may be static or dynamic in nature, as long as the muscular contraction is high in intensity and the duration of contraction is sufficient to activate the PAP mechanism (11,12,18,43).

Intensity of contraction is the most important factor in the selection of potentiating exercises. Intensities ranging from 60 – 100% of 1-repetition maximum (1RM) have been successful in eliciting PAP, although intensities greater than 85% are successful more often (8,10,12,15,27,43).

Multiple sets may be used in highly trained athletes to induce greater potentiation without causing excess peripheral fatigue (12,18). Performing as few as one set, and up to five sets, of an exercise has been successful in eliciting potentiation (12). Sets consisting of greater than five total repetitions or 5 seconds of total contraction time are not advisable because of the fatigue induced (11,18). Rather, sets of four repetitions, or 3 seconds or less of contractile time, will limit fatigue while still inducing potentiation (11,12,18,21,27). The duration of rest following potentiation depends primarily on the training status of the athlete and the intensity and volume of the potentiating exercise (12,27,36).

Duration

A recovery period immediately following the potentiating exercise should be given in order to eliminate associated fatigue (23). Enhancement of contractile ability is at its greatest immediately following the potentiating stimulus; however, fatigue is also greatest at the potentiating exercise's cessation and will outweigh the potentiation (36,45). In trained athletes the elimination of fatigue may be rapid enough to exhibit a portion of the initial heightened contractile ability, given a proper recovery period (12,18).

Recovery periods shorter than 2 – 3 min are usually not sufficient because the effects of fatigue outweigh the potentiation (23,27). Recovery periods longer than 12 min will usually not be successful because the enzyme responsible for deactivating the enhanced muscle fibers may have completely eliminated the effects of the initial potentiation (27).

In elite athletes there may be a wider window for potentiation (12,18). Rest durations examined for elite athletes have exhibited power performance enhancement from 2 – 20 min following the potentiating stimulus (12,18). In lesser-trained or recreational athletes, a time window for potentiation may not exist because the elimination of nervous and peripheral fatigue may be a slower process than the dephosphorylation of the muscle fibers (3,13,14,22,36,37). Ideal rest periods for a well-trained athlete are 3 –12 min, depending on the intensity and volume of the potentiating exercise (18,27).

Potentiated Exercises

Enhancement of power performance is the goal of using PAP (50). Thus, selection of the potentiated activity should encompass rapid forceful movement. Maximum force is not enhanced using PAP, whereas rate of force development and submaximal contractions may exhibit potentiation (17,31,36,48,49). Research indicates that repeated movements such as depth jumps or sprinting performance can be enhanced, as well as more traditional single-effort exercises such as the vertical countermovement jump (CMJ) or bench press throw (18,27,53,54).

Complex Training

CT was developed in an attempt to increase the intensity with which power exercises can be performed (50,51). CT is the training application of PAP. Of the few researchers that have implemented CT, all studies have reported that CT increases power performance at least as well as resistance training or plyometrics alone (5,29,32,41). However, it has been shown that plyometrics plus resistance training is also more effective than a single mode of training (20,28).

Only one study to date has compared CT to combined training with matched training volumes and intensities in a population of well-trained athletes. This study on NCAA Division I football players trended strongly toward but did not actually reach significantly increased CMJ height after seven weeks of CT, compared to combined training. According to the research, CT is at least as effective as combined training at increasing power performance (5).

CT may also be an effective way to manage the logistics of a large team in a small or crowded weight room because of its potential to decrease the demand for racks and platforms within a training session. One set of potentiating exercise may be sufficient for multiple sets of potentiated power exercises, creating less weightrack and platform demand (11,12,18).

Table 1. Sample Complexes

	Potentiating Exercise	Recovery	Potentiated Exercise	Total sets
Complex 1	1x4 back squat at 87% of1RM	4 – 6 min	2x6 depth jumps 3 min between sets	2 – 4 complexes
Complex 2	2x3 half back squatat 90% of 1RM, 2 – 3min between sets	5 – 8 min	1x40-yard sprint	2 – 3 complexes
Complex 3	3x1 deadlift at 95% of 1RM, 1 – 2minbetween sets	3 – 4 min	3x triple broad jump ≤ 1 min between	complete 1 – 2 complexes
Complex 4	3x3s MVC in half back squat position, 1 minbetween MVCs	6 – 10 min	2x5 squat jump 20% of back squat 1RM	repeat 2 – 3 complexes
Complex 5	1x3 back squat, 90% of 1RM	3 – 4 min	1x6 repeated countermovement jumps	repeat 3 – 6 complexes
Complex 6	2x3 bench press,90% of 1RM, 2 – 3 min between sets	5 – 8 min	3x6 bilateral medicineball chest pass 1 – 2 min between sets	complete 1 – 3 complexes
Complex 7	1x5 unilateral dumbbell bench press at 100% of 5RM	4 – 8 min	2x 6 unilateral medicineball chest pass 1 – 2 min between sets	complete 3 complexes, decreasing all reps by 1per complex

Conclusion

The use of a PAP protocol to increase power performance in well-trained athletes is acutely effective and as effective as other training methods to chronically increase power (5,29,32,41). PAP should be reserved for resistance-trained power athletes with high relative strength (21). When determining the recovery period duration following the potentiating exercise for balancing fatigue and enhancing muscular contractile ability, one should also take into account the intensity and volume of the potentiating exercise (12,36). CT may also be an effective tool for managing limited weight room time and space because it is at least as reliably effective as combined training (5,29,32,41).

References

1. Abbate, F, *et al. Effects of high frequency initial pulses and postetanic potentiation on power output of skeletal muscle.* Journal of Applied Physiology 88: 35–40, 2000.

2. Baker, D. Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. *Journal of Strength and Conditioning Research* 17: 493–497, 2003.

3. Brandenburg, JP. The acute effects of prior dynamic resistance exercise using different loads on subsequent upper-body explosive performance in resistance trained men. *Journal of Strength and Conditioning Research* 19: 427–432, 2005.

4. Brooks, GA, Fahey, TD, and Baldwin, KM. Exercise physiology: Human bioenergetics and its applications. (4th ed.) New York: McGraw Hill; 2005.

5. Burger, T. Complex training compared to a combined weight training and plyometric program, inPhysical Education. University of Idaho: Moscow; 1999.

6. Duthie, GM, Young, WB, and Aitken, DA. The acute effects of heavy loads on jump squat performance: an evaluation of the complex and contrast methods of power development. *Journal of Strength and Conditioning Research* 16: 530–538, 2002.

7. Ebben, WP, and Watts, PB. A review of combine weight training and plyometric training modes: Complex training. *Strength and Conditioning Journal* 20: 18–27, 1998.

8. Ebben, WP, Jensen, RL, and Blackard, DO. Electromyographic and kinetic analysis of complex training variables. *Journal of Strength and Conditioning Research* 14: 451–456, 2000.

9. Ebben, WP. Complex training: A brief review. *Journal of Sports Science and Medicine* 1: 42–46, 2002.

10. Evans, AK, et al. The acute effects of a 5RM bench press on power output (Abstract only). *Medicine and Science in Sports and Exercise* 1: S312, 2000.

11. French, DN, Kraemer, WJ, and Cooke, CB. Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *Journal of Strength and Conditioning Research* 17: 678–685, 2003.

12. Gilbert, G, and Lees, A. Changes in the force development characteristics of muscle following repeated maximum force and power exercise. *Ergonomics* 48: 1576–1584, 2005.

13. Gonzalez-Rave, JM, et al. Acute effects of heavy load exercises, stretching exercises, and heavy load plus stretching exercises on SJ and CMJ performance. *Journal of Strength and Conditioning Research* 23: 472–479, 2009.

14. Gossen, ER, and Sale, DG. Effect of postactivation potentiation on dynamic knee extension performance. *European Journal of Applied Physiology* 83: 524–530, 2000.

15. Gourgoulis, V, et al. Effect of a submaximal half-squats warm-up program on vertical jumping ability. *Journal of Strength and Conditioning Research* 17: 342–344, 2003.

16. Grange, RW, et al. Myosin phosphorylation augments force-displacement and force-velocity relationships of mouse muscle. *American Journal of Physiology: Cell Physiology* 269: C713–C724, 1995.

17. Grange, RW, Vandenboom, R, and Houston, ME. Physiologoical significance of myosin phosphorylation in skeletal muscle. *Canadian Journal of Applied Physiology* 18: 229–242, 1993.

18. Gullich, A, and Schmidtbleicher, D. MVC-induced short-term potentiation of explosive force. *New Studies in Athletics* 11: 67–81, 1996.

19. Hamada, T, et al. Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *Journal of Applied Physiology* 88: 2131–2137, 2000.

20. Harris, GR, et al. Short-term, performance effects of high power, high force, or combined weight-training methods. *Journal of Strength and Conditioning Research* 14: 14–20, 2000.

21. Harrison, A. Postactivation potentiation: predictors in NCAA division II track and field power athletes, in Physical Education, Health and Recreation. Western Washington University: Bellingham: 2011.

22. Hrysomallis, C, and Kidgell, D. Effect of heavy dynamic resistive exercise on acute upper-body power. *Journal of Strength and Conditioning Research* 15: 426–430, 2001.

23. Jensen, RL, and Ebben, WP. Kinetic analysis of complex training rest interval effect on vertical jump performance. *Journal of Strength and Conditioning Research* 17: 345–349, 2003.

24. Jones, P, and Lees, A. A biomechanical analysis of the acute effects of complext training using lower limb exercises. *Journal of Strength and Conditioning Research* 17: 694–700, 2003.

25. Khamoui, AV, Jo, E, and Brown, LE. Postactivation potentiation and athletic performance. NSCA Hot Topic Series, National Strength and Conditioning Association. 2009.

26. Khamoui, AV, et al. Effect of potentiating exercise volume on vertical jump performance parameters in recreationally trained men. *Journal of Strength and Conditioning Research* 23: 1465–1469, 2009.

27. Kilduff, LP, et al. Postactivation potentiation in professional rugby players: Optimal recovery. *Journal of Strength and Conditioning Research* 21: 1134–1138, 2007.

28. Kotzamanidis, C, et al. The effect of a combined high-intensity strength and speed training program on the running and jumping ability of soccer players. *Journal of Strength and Conditioning Research* 19: 369–375, 2005.

29. MacDonald, C, Lamont, HS, and Garner, JC. A comparison of the effects of 6 weeks of 3 different training modes on measures of strength and anthropometrics (Abstract only). *Journal of Strength and Conditioning Research* 24: 1, 2010.

30. Magnus, BC, et al. Investigation of vertical jump performance after completing heavy squat exercises. *Journal of Strength and Conditioning Research* 20: 597–600, 2006.

31. Metzger, JM, Greaser, ML, and Moss, RL. Variations in cross-bridge attachment rate and tension with phosphorylation of myosin in mammalian skinned skeletal muscle fibers. *Journal of General Physiology* 93: 855–883, 1989.

32. Mihalik, JP, et al. Comparing short-term complext training and compound training on vertical jump height and power output. *Journal of Strength and Conditioning Research* 22: 47–53, 2008.

33. Moore, RL, and Stull, JT. Myosin light chain phosphorylation in fast and slow skeletal muscles in situ. *American Journal of Physiology: Cell Physiology* 247: C462–C471, 1984.

34. Palmer, BM, and Moore, RL. Myosin light chain phosphorylation and tension potentiation in mouse skeletal muscle. *American Journal of Physiology: Cell Physiology* 257: C1012–C1019, 1989.

35. Radcliffe, JC, and Radcliffe, JL. Effects of different warm-up protocols on peak power output during a single response jump task (Abstract only). *Medicine and Science in Sports and Exercise* 28: S189, 1999.

36. Rassier, DE, and MacIntosh, BR. Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research* 33: 499–508, 2000.

37. Requena, B, et al. Effect of post-tetanic potentiation of pectoralis and triceps brachii muscles on bench press performance. *Journal of Strength and Conditioning Research* 19: 622–627, 2005.

38. Robbins, DW, and Docherty, D. Effect of loading on enhancement of power performance over three consecutive trials. *Journal of Strength and Conditioning Research* 19: 898–902, 2005.

39. Ryder, JW, et al. Enhanced skeletal muscle contraction with myosin light chain phosphorylation by a calmodulin-sensing kinase. *Journal of Biological Chemistry* 282: 20447–20454, 2007.

40. Sale, D. Postactivation potentiation: Role in performance. *British Journal of Sports Medicine* 38: 386–387, 2004.

41. Santos, EJM, and Janeira, MAAS. Effects of complex training on explosive strength in adolescent male basketball players. *Journal of Strength and Conditioning Research* 22: 903–909, 2008.

42. Scott, SL, and Docherty, D. Acute effects of heavy preloading on vertical and horizontal jump performance. *Journal of Strength and Conditioning Research* 18: 201–205, 2004.

43. Smilios, I, et al. Short-term effects of selected exercise and load in contrast training on vertical jump performance. *Journal of Strength and Conditioning Research* 19: 135–139, 2005.

44. Staron, RS, et al. Fiber type composition of the vastus lateralis muscle of young men and women. *The Journal of Histochemistry & Cytochemistry* 48(5): 623–629, 2000.

45. Sweeney, HL, Bowman, BF, and Stull, JT. Myosin light chain phosphorylation in vertebrate striated muscle: regulation and function. *American Journal of Physiology: Cell Physiology* 264: C1085–C1095, 1993.

46. Szczesna, D, et al. Phosphorylation of the regulatory light chains of myosin affects Ca2+ sensitivity of skeletal muscle contraction. *Journal of Applied Physiology* 92: 1661–1670, 2001.

47. Tillin, NA and Bishop, D. Factors modulating post-activation potentiation and its effect on performance of subsequen explosive activities. *Sports Medicine* 39: 147-166, 2009.

48. Vandenboom, R, Grange, RW, and Houston, ME. Myosin phosphorylation enhances rate of force development in fast-twitch skeletal muscle. *American Journal of Physiology: Cell Physiology* 268: C596–C693, 1995.

49. Vandenboom, R, Grange, RW, and Houston, ME. Threshold for force potentiation associated with skeletal muscle myosin phosphorylation. *American Journal of Physiology: Cell Physiology* 265: C1456–C1462, 1993.

50. Verkhoshansky, Y, and Tatyan, V. Speed-strength preparation of future champions. Legkaya Atletika 2: 12–13, 1973.

51. Verkhoshansky, Y. Speed-strength preparation and development of strength endurance of athletes in various specializations. *Soviet Sports Review* 22: 120–124, 1986.

52. Weber, KR, et al. Acute effects of heavy-load squats on consecutive jump performance. *Journal of Strength and Conditioning Research* 22: 726–730, 2008.

53. Yetter, M, and Moir, GL. The acute effects of heavy back and front squats on speed during 40-m sprint trials. *Journal of Strength and Conditioning Research* 22: 159–165, 2008.

54. Young, WB, Jenner, A, and Griffiths, K. Acute enhancement of power performance from heavy load squats. *Journal of Strength and Conditioning Research* 12: 82–84, 1998.

55. Zhi, G, et al. Myosin light chain kinase and myosin phosphorylation effect frequency-dependent potentiation of skeletal muscle contraction. *Proceedings of the National Academy of Science* 102: 17519–17524, 2005.