BRIEF REVIEWS

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Transfer of Strength and Power Training to Sports Performance

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The purposes of this review are to identify the factors that contribute to the transference of strength and power training to sports performance and to provide resistance-training guidelines. Using sprinting performance as an example, exercises involving bilateral contractions of the leg muscles resulting in vertical movement, such as squats and jump squats, have minimal transfer to performance. However, plyometric training, including unilateral exercises and horizontal movement of the whole body, elicits significant increases in sprint acceleration performance, thus highlighting the importance of movement pattern and contraction velocity specificity. Relatively large gains in power output in nonspecific movements (intramuscular coordination) can be accompanied by small changes in sprint performance. Research on neural adaptations to resistance training indicates that intermuscular coordination is an important component in achieving transfer to sports skills. Although the specificity of resistance training is important, general strength training is potentially useful for the purposes of increasing body mass, decreasing the risk of soft-tissue injuries, and developing core stability. Hypertrophy and general power exercises can enhance sports performance, but optimal transfer from training also requires a specific exercise program.

Key Words: resistance training, sprinting performance, neuromuscular factors, specificity, plyometrics

The ability to generate relatively high forces against large resistances (strength) and to produce a high work rate (power) is important for various sports. As such, resistance training has become an integral component of the physical preparation for enhancement of sports performance, and strength and conditioning training has become a specialization within sports training. A key issue for athletes and coaches at all levels is efficiency of training, that is, achieving the greatest gains in performance for a given amount of work effort. Therefore, the concept of maximizing the transfer of training to performance is paramount.

Transfer may be conceptually expressed as being a function of the following: gain in performance/gain in trained exercise (modified from Zatsiorsky[1]). For example, using the data of Wilson et al,[2] 8 weeks of strength training with the squat exercise produced a 21% gain in the one-repetition-maximum (1RM) squat. This

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change was accompanied by an improvement in vertical-jump (VJ) performance of 21% and 40-m sprint performance of 2.3%. This example shows that training to improve leg strength as measured by a 1RM squat has excellent transference to VJ performance but considerably less to sprinting performance. Key issues involve determining the factors responsible for attaining high levels of transfer and whether appropriate training guidelines have been identified. This article will address these issues.

Central to the concept of transfer is the well-accepted training principle of specificity, which states that adaptations are specific to the nature of the training stress. If this principle is followed to the extreme, all training would simply mimic competition demands. Although such an approach may be expected to yield a good transfer to performance in the short term and in experienced athletes, it might also be expected to produce negative outcomes such as overtraining, muscle imbalances, increased injury risk, and boredom in the long term.[3] If only specific training were used by athletes, many popular resistance-training modalities would never be used.

Approximately 60 years ago, coaches acknowledged that there was a role for general or nonspecific training to provide a "foundation" of fitness.[4] More recently, general training has come to be thought valuable because it allows the development of a balanced neuromuscular system and serves as a base from which to train more specifically at later stages.[3] Beginner athletes can achieve good transfer from general training, whereas experienced athletes attain specific adaptations.[1,5] This suggests that the principle of specificity of training becomes more relevant according to the levels of training experience and performance.[6]

The remainder of this review will examine previous research to understand the transfer of strength and power training to sports performance, discuss a physiological basis for transfer, and suggest training implications. It is beyond the scope of this article to explore all aspects of sports performance, so I will use sprinting, which is a fundamental component of many sports, as an example.

Sprinting

Considerable research has indicated significant correlations between sprinting performance over various distances and a range of measures of strength[7-10] and power.[8-12] Significant relationships between strength and power and sprint performance imply that the muscle function assessed by strength and power tests has some commonality with performance. This might suggest that improvement in strength and power may lead to improvement in sprint performance, but because correlation does not indicate cause and effect, it is necessary to examine longitudinal studies involving resistance-training programs.

Sprint performance can be considered to contain 3 independent components: acceleration, maximum speed, and speed maintenance.[13] Statistical analysis of 100-m sprint running has confirmed this classification.[14] Squats and jump squats (JS, loaded vertical jumps) are popular exercises for training strength and power, respectively, and have also been used in training studies. High-resistance weight training of the leg-extensor muscles is effective for improving maximum strength in a squat test, but this has not transferred to sprint speed.[15-16] For example, Harris et al[16] reported that 9 weeks of training with various squat and pulling exercises produced an approximately 10% gain in squat strength, but this was associated with no change in 30-m sprint performance. One study[2] was able to demonstrate statistically significant gains in 40-m sprint performance after 8 weeks of squat training. To achieve a 2.2% gain in sprint performance, however, a 21% improvement in squat strength was required.

Although sprint performance may be more related to power than to strength, similar findings have been reported for power training. Training with either JS or plyometric exercise has been shown to produce significant gains in jump tests of leg power with small and nonsignificant changes in sprint performance.[15-18] Experienced male sprinters who trained with various weight-training machines that involved hip and knee extensors and flexors were able to improve their 1RM squat by 12.4%.[19] The corresponding improvements in acceleration and maximum speed, however, were only 4.3% and 1.9%, respectively. One study[15] required subjects to perform JS with the load that yielded maximum power output over a 10-week period. The mean improvement in JS height using a 4-kg bar was 16.8%, but this was associated with only a 1.1% change in 30-m sprint time. In all of these studies,[15-18] the power training consisted of exercises involving VJ performed bilaterally.

The poor transfer of power training could relate to a lack of movement specificity to sprinting, which involves unilateral contractions of the leg extensors resulting in total body movement in a horizontal direction. This suggestion is consistent with the findings of Rimmer and Sleivert,[20] who reported that 8 weeks of plyometric training including some unilateral/horizontal exercises induced significant improvements (2.6%) in sprint time to 10 m. Furthermore, a 9-week sprint and plyometric program including both unilateral and horizontal exercises improved sprint performance to 10 m significantly more than sprinting alone, and, interestingly, the improved 10-m performance did carry over to 100-m performance.[14] In these plyometric training studies,[14,20] however, the benefits to short sprints did not extend to maximum speed.

The ability of some plyometric exercises to transfer to sprinting might partially reflect the contraction velocity specificity. Bounding exercises have been found to possess ground-contact times very similar to those of the acceleration phase of sprinting.[21-22] In contrast, even low-resistance JS involve push-off times that are relatively long, such as >0.7 second.[15] This point is worthy of elaboration. The rationale for using relatively light loads in resistance exercises is to produce a combination of contraction force and movement velocity that approximates maximum power output.[15-16] Cronin et al[23] conducted a study with nonresistance-trained females who performed bench-press throws with 60% of the predicted 1RM for 6 weeks. This load is considered “light” because in untrained women, 20 bench-press repetitions can be performed with this load.[24] Bench-press throws with 60% of 1RM allowed a mean bar velocity of 0.4 m/s to be generated.[23] When the same subjects executed a maximum-effort netball pass, the average ball speed generated was 11.4 m/s.[23] In this example, the “light load/high speed” resistance exercise produced a movement speed representing only 3.5% of the speed attained in the netball pass. This shortcoming highlights the difficulty of achieving sport-specific movement velocities with many resistance-training exercises.

Alternatives to exercises such as JS or bench-press throws with barbells are plyometric exercise (discussed above) and the performance of the sport skill with added load. An example of the latter is sprinting while pulling a loaded sled. A study that compared unresisted and sled-resisted sprinting[25] indicated that a sled load of 12.5% of body mass produced a running velocity that was 90% of the unresisted velocity over 15 m. The authors concluded that this load would be suitable for training because it produced minimal disruption to sprint mechanics but still provided the necessary overload. Furthermore, it appears that achieving movement and velocity specificity is easier with this mode of resistance training. A recent study[26] evaluated the effects of sled sprint training with a 5-kg load (about 7% of body mass) on sprint performance. Eight repetitions of 20- to 50-m sprints performed over an 8-week period produced a significant 2.0% gain in running velocity over the first 20 m, but no improvement in maximum speed was attained. These findings are expected because sprinting mechanics using a sled are more similar to the acceleration phase (eg, more forward lean) than the maximum-speed phase of sprinting.[26]

Resisted sports movements such as sled sprinting could potentially hinder sports performance if the skill is dramatically changed. This concern is probably unfounded for 2 reasons. First, the greater the additional load used in sled sprinting, the greater the modification to the unresisted sport skill.[25,27] Therefore, the use of a relatively light load, such as the 12.5% of body mass recommended by Lockie et al,[25] should ensure minimal alteration of the correct mechanics. Second, the volume of this type of resistance training would be far less than the quantity of unresisted sprint training, which would further minimize any expected biomechanical disruption over time. Nevertheless, more longitudinal research concerning the potential benefits of many resisted-sprinting methods is needed.

Physiological Basis of Transfer

Strength and power production in sport are influenced by a range of neuromuscular factors. In simple terms, muscle performance is determined by a combination of muscle cross-sectional area and the extent to which the muscle mass is activated, that is, neural factors.[28-30] Sprinting is influenced by neuromuscular function, and, because of its complexity, many different muscles must be activated at the appropriate times and intensities to maximize speed.[13]

Because muscle cross-sectional area is related to voluntary strength,[31] hypertrophy training methods potentially increase force and power output in a sports movement. With regard to enhancing sports performance, an important consideration with hypertrophy training is the concept of optimum muscle and total body mass. Gains in muscle size are associated with gains in body mass, and such changes may or may not enhance sports performance, depending on the needs of the individual. For example, hypertrophy methods might be appropriate for a shot-putter seeking gains in absolute strength and power, but they could reduce the power:weight ratio of a high jumper and therefore inhibit high-jump performance.[32]

According to Carroll et al,[33] the physiological adaptations associated with resistance training can potentially produce either positive or negative transfer to sports performance. Negative transfer could occur if there is increased coactivation of antagonist muscles because this would produce force that opposes the intended movement direction.[28] For example, Baratta et al[34] showed that knee-flexion training produced greater knee-flexion activation during a knee-extension strength test. This observation indicates that the training of the hamstrings caused this muscle group to produce greater antagonistic coactivation during the knee-extension task. Positive transfer can occur if resistance training reinforces the optimum muscle-activation patterns that are required in the execution of the sport skill.[33] This could be achieved by either increased excitatory neural activation of muscles that contribute to skillful performance and/or by inhibition of muscles that can degrade performance.[33] Apart from decreased cocontraction of antagonists, transfer might be enhanced by improved interaction between synergists.[30] Generally, the improved coordination of muscles involved in a sports movement has been termed *intermuscular coordination*[35] and is considered important for sprint performance.[13]

The importance of intermuscular coordination for achieving transfer from training to athletic performance is demonstrated by 2 studies involving different methodologies. In the first study, Bobbert and Van Soest[36] used a computer simulation of VJ performance from input of force produced over time by 6 lower extremity muscles. First, the model was optimized to maximize jump height using parameters similar to those recorded from well-trained volleyball players. When only muscle force was increased to simulate increased muscle strength, it was found that jump height decreased. For example, a 20% increase in knee-extensor force in isolation produced a 9-cm decrease in jump height. When the model was reoptimized using this enhanced muscle force, jump height was improved by 3 cm beyond the original performance. This finding indicates that jump performance could be impaired by altered intermuscular coordination, despite increased force output from individual muscles. The authors concluded that to improve jumping performance, a precise tuning of the control of muscle properties must be achieved.

The second study[37] required subjects to perform 3 sets of 10 repetitions of an isokinetic knee-extension and -flexion exercise at 100°/s for 6 weeks. After 6 weeks of training each leg unilaterally, the mean gain in quadriceps and hamstrings isokinetic strength assessed at the training velocity was between 7% and 11.8% and was statistically significant for the quadriceps. Improvements in standing long-jump performance were more modest (2.3%) and not significant, despite the fact that this activity significantly involves the quadriceps and hamstring muscles. Because the subjects in this study did not practice jumping during the training period, it could be speculated that the intermuscular coordination was not optimal and may have limited the transfer from the training. The relatively poor transfer might also be explained by a violation of the specificity principle. Sale and MacDougall[38] suggested that training should be specific in terms of movement pattern, contraction velocity, contraction type, and contraction force. The training exercise differed from the standing long jump with regard to all of these factors.

Intermuscular coordination refers to the interaction between muscles that control a movement, but neural adaptations confined to a single muscle might also explain performance enhancement from training and have thus been termed *intramuscular coordination*.[35] These include such factors as increased motor-unit recruitment, firing rates, and synchronization, as well as reflex potentiation[30,35] and decreased inhibition from eccentric loads during stretch–shorten cycle contractions to optimize musculotendinous stiffness.[39]

Although the measurement of these individual mechanisms is complex, changes in neural activation as recorded by surface electromyography (EMG) have been clearly demonstrated in resistance-training studies.[18,29,40] Yet despite significant gains in the neural activation of individual muscles, transfer to specific sports movements can be limited. For example, McBride et al[18] reported that subjects who trained for 8 weeks with JS using 80% of their 1RM squat achieved an increase of greater than 60% in the average EMG output of the vastus lateralis while performing JS. This was accompanied by a smaller 10% gain (statistically significant) in peak power output while jumping and no improvement in jump height or sprinting performance. This finding indicates that intramuscular coordination factors might be relatively less influential than intermuscular factors and reinforces the importance of movement-pattern specificity for transfer to jumping and sprinting performance.

The Role of General Resistance Training

The specificity of resistance training for transfer to sports performance has been highlighted. Therefore, what is the role, if any, for general or nonspecific resistance training? First, general strength training has been shown to transfer to performance in skills such as VJ[5] and baseball-throwing velocity.[41] For example, strength training using bench-press and pull-over exercises for 8 weeks produced a 22.8% gain in 6RM strength, and this was accompanied by a significant improvement (4.1%) of baseball-throwing velocity.[42] The subjects in this study had a mean age of 18.6 years and no previous experience in resistance training. It is not clear whether similar gains could occur from general strength training in highly strength-trained baseball players.

Another proposed benefit of general strength training is a reduction in the risk of sports injuries such as damage to soft tissues. As such, a significant portion of an athlete's time in physical preparation might be devoted to this goal. For example, eccentric strength training for the hamstrings has been recommended for the prevention and rehabilitation from hamstring strains[43] and has been shown to be effective for injury reduction using a prospective randomized controlled research design.[44] General strength training of the muscles of the lower extremity has also been shown to be just as effective[45] or more effective[46] than balance training for enhancing balance and proprioception. Because balance capabilities have been linked to sports-injury risk,[47] strength training might have a prophylactic benefit.

The development of core stability has also become a focus of many strength and conditioning programs, especially in junior athletes.[48] Core stability is thought to be important for sprint-running efficiency.[49] Research using a prospective design[50] indicated that hip-abduction and external-rotation strength were significantly lower in athletes who were subsequently injured during a season and led the authors to conclude that core stability has an important role in injury prevention. However, 6 weeks of core-stability training in recreational athletes has been shown to enhance measures of core stability, without significant transfer to running economy or performance.[51]

Although a strong connection between core-stability training and injury prevention is yet to be established by researchers, 2 key issues for strength and conditioning professionals have emerged. The first is determining the proportion of the program devoted to injury prevention and general training compared with specific training designed to maximize transfer to sports performance directly. The second is the appropriate ways in which to develop core stability, as there is a large range of exercise possibilities.[52]

Conclusions and Practical Applications

General strength training might be beneficial for athletes because of the potential to enhance the force-generating capabilities of muscle, increase total body mass, reduce the risk of sports injuries, and improve core stability. However, direct transfer to improve sports performance might be limited by such training in experienced athletes. Although nonspecific resistance training can induce neural adaptations and increase the power production of individual muscles, it appears that to maximize transfer to specific sports skills, training should be as specific as possible, especially with regard to movement pattern and contraction velocity. This type of training can be expected to enhance intermuscular coordination and ensure that muscles are "tuned" to any newly acquired force-generating capacity. Adding a load to a sports movement would seem to be a suitable strategy to achieve this specificity, although the amount and direction of added resistance would need to be considered. The potential benefit of resisted sports movements such as sprinting requires further research.

Ultimately, a combination of general and specific resistance-training methods can be recommended to develop all the neuromuscular factors contributing to sports skills requiring strength and power.[23,41,53] The way in which these methods are integrated over time is an issue of periodization that must be considered[3] and is likely to depend on the needs and developmental level of the individual athlete. A developing athlete might be advised to emphasize core stability, muscle hypertrophy (if increased body mass is advantageous), and intramuscular coordination. Provided a solid foundation has been developed, a highly resistance-trained athlete might be expected to benefit more from training intermuscular coordination.

It may be useful to think of training an athlete to improve sprinting performance by using an analogy of a competitive sports car (Table 1). General training

Table 1 Strategies for Developing Power in a Sprinter Based on Neuromuscular Factors Using an Analogy of a Race Car

Race-car performance	Sprinting performance	Example of neuromuscular factors	Training methods
↑ engine capacity	↑ muscle cross-sectional area	↑ muscle cross-sectional area	Hypertrophy with squats
↑ engine power output, eg, optimum timing of all cylinders	↑ intramuscular coordination of involved muscles	↑ motor-unit recruitment, firing rates, synchronization, reflex potentiation	Jump squats with load that maximizes power output
↑ conversion of power from engine to road, eg, effective transmission	↑ intermuscular coordination	↑ activation of synergists, ↓ cocontraction of antagonists	Resisted sprints, unilateral/horizontal plyometrics, eg, speed bounding

may include hypertrophy to increase the force-generation capacities of important muscles, as well as strengthening core muscles (not shown). The second training strategy is to develop the "neural activation capacity" of the relevant muscles. Although these combined approaches might build a powerful athlete, maximization of transfer to sports performance requires the "conversion" of powerful muscles to a coordinated sports skill.

References

1. Zatsiorsky VM. *Science and Practice of Strength Training*. Champaign, Ill: Human Kinetics; 1995.
2. Wilson GJ, Murphy AJ, Walshe A. The specificity of strength training: the effect of posture. *Eur J Appl Physiol*. 1996;73:346-352.
3. Bompa TO. *Periodization of Strength*. Toronto, Ont: Veritas Publishing; 1993.
4. Lowe DGA. *Track and Field Athletics*. London, UK: Pitman; 1947.
5. Baker D. Improving vertical jump performance through general, special, and specific strength training: a brief review. *J Strength Cond Res*. 1996;10(2):131-136.
6. Siff MC, Verkhohansky YV. *Supertraining*. Denver, Col: Supertraining International; 1999.
7. Alexander MJL. The relationship between muscle strength and sprint kinematics in elite sprinters. *Can J Sport Sci*. 1989;14, 3:148-157.
8. Meckel Y, Atterbom H, Grodjinovsky A, Ben-Sira D, Rotstein A. Physiological characteristics of female 100 metre sprinters of different performance levels. *J Sports Med Phys Fitness*. 1995;35:169-175.
9. Young W, McLean B, Ardagna J. Relationship between strength qualities and sprinting performance. *J Sports Med Phys Fitness*. 1995;35:13-19.
10. Bret C, Rahmani A, Dufour AB, Messonnier L, Lacour JR. Leg strength and stiffness as ability factors in 100 m sprint running. *J Sports Med Phys Fitness*. 2002;42:274-281.
11. Kukolj M, Ropret R, Ugarkovic D, Jaric S. Anthropometric, strength, and power predictors of sprinting performance. *J Sports Med Phys Fitness*. 1999;39:120-122.
12. Hennessy L, Kilty J. Relationship of the stretch-shortening cycle to sprint performance in trained female athletes. *J Strength Cond Res*. 2001;15(3):326-331.
13. Ross A, Leveritt, Riek S. Neural influences on sprint running—training adaptations and acute responses. *Sports Med*. 2001;31,6:409-425.
14. Delecluse C, Van Coppenolle H, Willems E, Van Leemputte M, Diels R, Goris M. Influence of high-resistance and high-velocity training on sprint performance. *Med Sci Sports Exerc*. 1995;27(8):1203-1209.
15. Wilson GJ, Newton, RU, Murphy AJ, Humphries BJ. The optimum training load for the development of dynamic athletic performance. *Med Sci Sports Exerc*. 1993;25(11):1279-1286.
16. Harris GR, Stone, MH, O'Bryant HS, Proulx CM, Johnson RL. Short-term performance effects of high power, high force, or combined weight-training methods. *J Strength Cond Res*. 2000;14(1):14-20.
17. Lyttle AD, Wilson GJ, Ostrowsky KJ. Enhancing performance: maximal power versus combined weights and plyometrics training. *J Strength Cond Res*. 1996;10(3):173-179.
18. McBride, JM, Triplett-McBride T, Davie A, Newton RU. The effect of heavy- vs light-load jump squats on the development of strength, power, and speed. *J Strength Cond Res*. 2002;16(1):75-82.
19. Blazevich AJ, Jenkins DG. Effect of the movement speed of resistance training exercises on sprint and strength performance in concurrently training elite junior sprinters. *J Sports Sci*. 2002;20:981-990.

20. Rimmer E, Sleivert G. Effects of a plyometrics intervention program on sprint performance. *J Strength Cond Res*. 2000;14,3:295-301.
21. Young W. Sprint bounding and the sprint bound index. *Nat Strength Cond Assoc J*. 1992;14(4):18-21.
22. Mero A, Komi PV. EMG, force, power analysis of sprint-specific strength exercises. *J Appl Biomech*. 1994;10:1-13.
23. Cronin J, McNair PJ, Marshall RN. Velocity specificity, combination training and sport specific tasks. *J Sci Med Sport*. 2001;4(2):168-178.
24. Hoeger WWK, Hopkins DR, Barette SL, Hale DF. Relationship between repetitions and selected percentages of one repetition maximum: a comparison between untrained and trained males and females. *J Appl Sports Sci Res*. 1990;4(2):47-54.
25. Lockie RG, Murphy AJ, Spinks CD. Effects of resisted sled towing on sprint kinematics in field-sport athletes. *J Strength Cond Res*. 2003;17(4):760-767.
26. Zafeiridis A, Saraslanidis P, Manou V, Ioakimidis P, Dipla K, Kellis S. The effects of resisted sled-pulling sprint training on acceleration and maximum speed performance. *J Sports Med Phys Fitness*. 2005;45:284-290.
27. Letzelter M, Sauerwein G, Burger R. Resistance runs in speed development. *Mod Athlete Coach*. 1995;33:7-12.
28. Sale DG. Influence of exercise and training on motor unit activation. In: Pandolf KB, ed. *Exerc Sport Sci Rev*. 1987;15:95-151.
29. Häkkinen K. Neuromuscular and hormonal adaptations during strength and power training. *J Sports Med Phys Fitness*. 1989;29:9-26.
30. Behm DG. Neuromuscular implications and applications of resistance training. *J Strength Cond Res*. 1995;9(4):264-274.
31. Ikai M, Fukunaga T. Calculation of muscle strength per unit cross-sectional area of human muscle by means of ultrasonic measurement. *Int Z Angew Physiol*. 1968;26:26-32.
32. Young W. Speed, strength and power training. In: Pyke FS, ed. *Better Coaching. Advanced Coaches Manual*. 2nd ed. Champaign, Ill: Human Kinetics; 2001:123-136.
33. Carroll TJ, Riek S, Carson RG. Neural adaptations to resistance training. Implications for movement control. *Sports Med*. 2001;31(12):829-840.
34. Baratta R, Solomonow M, Zhou BH, Letson D, Chuinard R, D'Ambrosia R. Muscular coactivation: the role of the antagonist musculature in maintaining knee stability. *Am J Sports Med*. 1988;16(2):113-122.
35. Schmidtbleicher D. Training for power events. In: Komi PV, ed. *Strength and Power in Sport*. Oxford, UK: Blackwell; 1992:381-395.
36. Bobbert MF, Van Soest AJ. Effects of muscle strengthening on vertical jump height: a simulation study. *Med Sci Sports Exerc*. 1994;26(8):1012-1020.
37. Morris CJ, Tolfrey K, Coppack RJ. Effects of short-term isokinetic training on standing long-jump performance in untrained men. *J Strength Cond Res*. 2001;15(4):498-502.
38. Sale D, MacDougall D. Specificity in strength training: a review for the coach and athlete. *Can J Appl Sport Sci*. 1981;16(2):87-92.
39. Gollhofer A, Schmidtbleicher D. Muscle activation patterns of human leg extensors and force-time-characteristics in jumping exercises under increased stretch loads. In: DeGroot G, Hollander A, Huijing P, Van Ingen Schenau G, eds. *Biomechanics XI-A*. Amsterdam: Free University Press; 1988:143-147.
40. Thorstensson A, Karlsson J, Viitasalo JHT, Luhtanen P, Komi PV. Effect of strength training on EMG of human skeletal muscle. *Acta Physiol Scand*. 1976;98:232-236.
41. DeRenne C, Kwok WHO, Murphy JC. Effects of general, special, and specific resistance training on throwing velocity in baseball: a brief review. *J Strength Cond Res*. 2001;15(1):148-156.

42. Newton RU, McEvoy KP. Baseball throwing velocity: a comparison of medicine ball training and weight training. *J Strength Cond Res*. 1994;8:198-203.
43. Brockett CL, Morgan DL, Proske U. Predicting hamstring strain in elite athletes. *Med Sci Sports Exerc*. 2004;36(3):379-387.
44. Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scand J Med Sci Sports*. 2003;13(4):244-250.
45. Blackburn T, Guskiewicz KM, Petschauer MA, Prentice WE. Balance and joint stability: the relative contributions of proprioception and muscular strength. *J Sport Rehabil*. 2000;9:315-328.
46. Bruhn S, Kullmann N, Gollhofer A. The effects of sensorimotor training and strength training on postural stabilisation, maximum isometric contraction and jump performance. *Int J Sports Med*. 2004;25:56-60.
47. McGuine TA, Green JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sports Med*. 2000;10:239-244.
48. Jeffreys I. Developing a progressive core stability program. *Strength Cond J*. 2002;24(5):65-66.
49. Faccioni A. The role of the mid-torso in maximising sprint performance. *Strength Cond Coach*. 1994;2(2):6-10.
50. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injuries in athletes. *Med Sci Sports Exerc*. 2004;36(6):926-934.
51. Stanton R, Reaburn PR, Humphries B. The effect of short-term Swiss ball training on core stability and running economy. *J Strength Cond Res*. 2004;18(3):522-528.
52. Baker D. Overuse of Swiss ball training to develop core stability or improve sports performance. *Strength Cond Coach*. 2000;8(2):5-9.
53. Young W. The planning of resistance training for power sports. *Natl Strength Cond Assoc J*. 1991;13(4):26-29.