Does Performance of Hang Power Clean Differentiate Performance of Jumping, Sprinting, and Changing of Direction?

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Abstract

The primary purpose of this study was to investigate whether the athlete who has high performance in hang power clean, a common weightlifting exercise, has high performances in sprinting, jumping, and changing of direction (COD). As the secondary purpose, relationships between hang power clean performance, maximum strength, power and performance of jumping, sprinting, and COD also were investigated. Twenty-nine semiprofessional Australian Rules football players (age, height, and body mass [mean ± SD]: 21.3 ± 2.7 years, 1.8 ± 0.1 m, and 83.6 ± 8.2 kg) were tested for one repetition maximum (1RM) hang power clean, 1RM front squat, power output during countermovement jump with 40-kg barbell and without external load (CMJ), height of CMJ, 20-m sprint time, and 5–5 COD time. The subjects were divided into top and bottom half groups (n = 14 for each group) based on their 1RM hang power clean score relative to body mass, then measures from all other tests were compared with one-way analyses of variance. In addition, Pearson's product moment correlations between measurements were calculated among all subjects (n = 29). The top half group possessed higher maximum strength ($P < 0.01$), power ($P < 0.01$), performance of jumping ($P < 0.05$), and sprinting ($P < 0.01$). However, there was no significant difference between groups in 5–5 COD time, possibly because of important contributing factors other than strength and power. There were significant correlations between most of, but not all, combinations of performances of hang power clean, jumping, sprinting, COD, maximum strength, and power. Therefore, it seems likely there are underlying strength qualities that are common to the hang power clean, jumping, and sprinting.

Key Words weightlifting, jump squat, counter movement jump, power, maximum strength, athletic performance

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Introduction

Performance of jumping, sprinting, and changing of direction (COD) impacts considerably on success in team sports such as American football, Australian Rules football, volleyball, and basketball (11,12,17,37). It has been well documented that power is one of the important factors in the athletic performance (1,5,6,23,37). Power is the mechanical quantity that expresses the rate of doing work (10) and is largely dependant on the ability to exert the highest possible force (i.e., maximum strength) (25,29,30). Thus, how maximum strength and power are effectively developed are important issues for athletes and coaches in those sports. To optimize the athletes' performance in competition, it is important to develop maximum strength during the early phase of long-term training and transfer maximum strength to power effectively as the competition becomes closer (16,24). There is agreement among researchers and practitioners (16,24,33) that the use of training exercises involving heavy resistance such as the squat is an effective method to develop maximum strength. On the other hand, training exercises should involve rapid acceleration extended through the entire movement to develop power, and weightlifting exercises are commonly prescribed for this purpose (19).

Weightlifting exercises include 2 competition lifts in the sport of weightlifting (i.e., "snatch" and "clean and jerk") and the variation of these exercises, such as hang power clean. The weightlifting exercises involve exerting high forces against the ground and applying these forces rapidly, so that it appears an ideal form of exercise to exhibit high power output (19). For example, Garhammer (14) reported that snatch and clean-and-jerk exhibit much greater power outputs compared with squat and deadlift. The movement of weightlifting exercises allows an athlete to accelerate the barbell through the entire range of pulling or driving movement and does not require the athlete to decelerate the barbell velocity actively. Once the athlete completes the acceleration of the barbell, the barbell's upward movement is controlled by the influence of gravity (19). Because of these characteristics, it has been speculated that weightlifting exercises are beneficial to improve an athlete's capability of power production

(4,19,23). As a result, many strength and conditioning programs incorporate weightlifting exercises for their athletes. For example, most of the strength and conditioning coaches in the National Football League (88%), National Basketball Association (95%), and National Hockey League (100%) in North America report having used weightlifting exercises in their programs (8,9,26).

The purpose of this study was to investigate whether the athlete who has high performance in hang power clean has high performances in sprinting, jumping, and COD. The hang power clean is a common weightlifting exercise among athletes, and the technique of this exercise is relatively easy to learn compared with other weightlifting exercises. This was the rationale for using the hang power clean in this study. If the athletes who has high performance in hang power clean has high performance in jumping, sprinting, and COD, it could be speculated that the strength qualities required for high performance in such a weightlifting exercise are the same strength qualities critical for high performance in jumping, sprinting, and COD. At present, scientific research to support the efficacy of the weightlifting exercises is scarce. Although several studies (2,3,13,15,18,21,28, 31) have examined the relationships between the biomechanical characteristics of weightlifting exercise and jumping, there is limited information available about the relationships between the performance of weightlifting exercises, sprinting and COD (1,18,31). It was envisaged that the findings of this investigation would help elucidate why the weightlifting exercises have been so popular. Second, the study would help determine whether the weightlifting exercises share common strength qualities with jumping, sprinting, and COD. Finally, the results would allow us to speculate on the efficacy of the HPC for developing maximum strength, power and performance of jumping, sprinting, and COD.

Methods

Experimental Approach to the Problem

Twenty-nine semiprofessional Australian Rules football players participated in the present study. We tested 7 measurements consisting of one repetition maximum (1RM) hang power clean to evaluate performance of weightlifting exercise; 1RM front squat to evaluate maximum strength; power output during the counter movement jump with a 40-kg barbell (CMJ 40), and without external load (CMJ) to evaluate maximal power; jump height of CMJ to evaluate jump performance; 20-m sprint time to evaluate sprint performance; and 5–5 COD (Figure 1) time to evaluate COD performance. The subjects were then divided into 2 groups based on whether they were above or below the median score for 1RM hang power clean. Values obtained from all other tests were then compared between these 2 groups. In addition, correlations between measurements among all subjects were calculated to examine the strength of relationships.

Subjects

Twenty-nine male semi-professional Australian Rules football players were recruited. Their age, height, and body mass (mean ± SD) were, 21.3 ± 2.7 years, 1.8 ± 0.1 m, and 83.6 ± 8.2 kg. The present study was conducted during January and February 2006. All subjects were familiar with basic resistance exercises such as bench press and back squat from their previous seasons. During their off season strength and conditioning program (October 2005 to January 2006), the subjects performed hang power clean and front squat 2–3 times per week under the supervision of their club's coaching staff. At the time of data collection, all subjects were able to perform hang power clean and front squat appropriately and none of them had any illness or injuries which would affect the test results. After the data collection of the present study, the subjects' strength and conditioning program moved to the specific preparation phase to prepare their 2006 season in which the first match was held in April 2006. This study was approved by Edith Cowan University Human Research Ethics Committee. All subjects read the information letter explaining the procedure of the study, and signed the informed consent document.

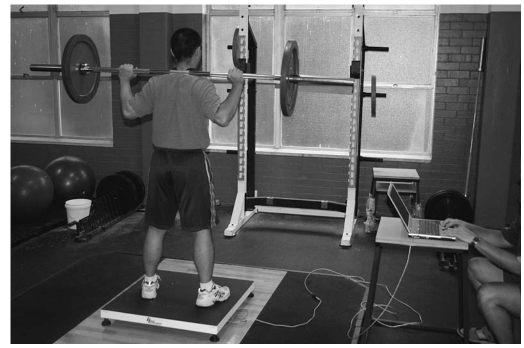

Figure 1. Weighted jump squat.

Tests and the Order

The testing was administered over 3 different days, and each test day was separated by at least 48 hours to minimize the effects of fatigue. Each test day consisted of the following measurements:

- Day 1: 20 m sprint and 5–5 COD
- Day 2: CMJ and CMJ 40
- Day 3: 1RM hang power clean and 1RM front squat

Before the start of each test day, subjects were instructed to warm-up with several minutes of aerobic exercises (jogging, biking, or rowing) and dynamic stretching.

Test Procedure

1 RM Hang Power Clean. Hang power clean began from a position such that the subjects stood and held the barbell in front of his body. The subject started the movement by lowering the barbell to above his knee. From above the knee, the subject moved the barbell upward explosively, and received the barbell at his shoulder height (21). The

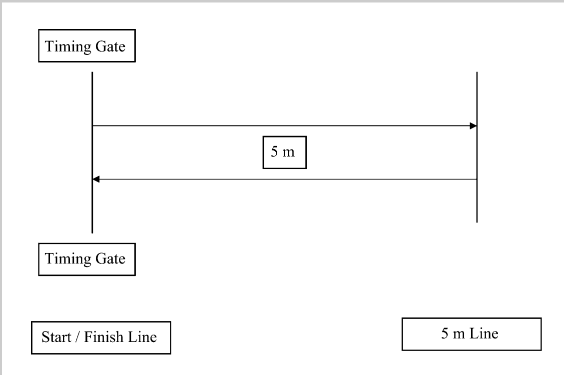

Figure 2. Description of 5–5 change of direction.

investigator estimated the subject's 1RM from his recent training log, and planned the weights to be lifted during a series of warm-up sets. In each set, the subject performed one to three repetitions, and the weight was increased every set. The subject started the warm-up with the set using bar only (20 kg), added 20–40 kg each set until the load was about 60% of estimated 1RM and then added 5–10 kg until the load was 90% of estimated 1RM. After these sets were completed, the weight was increased by 2.5 or 5 kg after each set until their 1RM was determined. The absolute value and the value divided by the subject's body mass were used for the statistical analysis.

1 RM Front Squat. The subject's feet position and grip width were self selected. The subject placed the barbell on his anterior part of deltoid muscles and clavicles. Then, he squatted until his posterior surface of thigh became parallel to the floor, and stood up to his starting position. The movement was observed by the investigator to ensure test compliance. Prior to the test, the subject completed a few warm-up sets as explained in the 1RM hang power clean. The absolute value and the value divided by the subject's body mass were used for the statistical analysis.

Counter Movement Jump With 40-kg Weight. The subject's feet position, barbell position and grip width were self selected. He squatted down to his comfortable depth, and then jumped vertically as high as possible. The CMJ 40 was performed on a force platform (Performance Plate, Fitness Technology, Adelaide, Australia) so as to record ground reaction force (GRF, Figure 1). Vertical component of ground reaction force was sampled at 200 Hz for 5 seconds using the computer software (Ballistic Measurement System, Innervations, Perth, Australia), and the vertical component of peak power output was obtained using the following process; velocity of the center of gravity (COG) of the system was calculated from GRF-time data based on the relationship between impulse and momentum in which impulse is equal to the changes in momentum, and power applied to the COG of the system was calculated as the product of velocity of the COG of the system and GRF at each time point (7,20). The subjects performed the CMJ 40 twice, and the intraclass correlation coefficient (ICC) obtained from the 2 repetitions was 0.97. The higher peak power value of the 2 repetitions (absolute value and the value divided by the subject's body mass) was used for the statistical analysis.

Counter Movement Jump. Peak power during CMJ was also calculated using the force platform and computer software described previously. In addition, the peak displacement (jump height) was estimated from changes in the velocity of the COG of the system. The subject squatted to his comfortable depth, and then without pausing, jumped as high as possible. The subject placed a light fiberglass stick on their shoulders, and kept holding the stick throughout the tests to eliminate the effects of arm swing and isolate force production by the lower extremities (37). The subject performed the CMJ twice, and the ICC was obtained from the two repetitions (0.95 for peak power and 0.85 for jump height). The peak power value (absolute value and the value divided by the subjects' body mass) and jump height during the trial which exerted higher peak power value were used for statistical analysis.

20-m Sprint. The 20-m sprint performance was measured by using the 2 pairs of timing gates (Kinematic Measurement System, Fitness Technology, Adelaide, Australia). Timing gates were placed 0 m and 20 m from start line. Details about this equipment have been published elsewhere (6). The subject started in a standing position with the toes of the

Table 1. Comparison between top 50% and bottom 50% in the 1RM hang power clean.

	Top 50% (mean ± *SD*)	Bottom 50% (mean ± *SD*)
HPC 1RM†	80.2 ± 8.6	70.2 ± 5.9
HPC 1RM/BM†	1.0 ± 0.1	0.8 ± 0.1
FS 1RM*	105.4 ± 7.2	96.6 ± 13.7
FS 1RM/BM†	1.3 ± 0.1	1.1 ± 0.2
CMJ 40 kg PP (W)	3952 ± 522	3752 ± 375
CMJ 40 kg PP (W/kg)†	49.9 ± 4.8	43.8 ± 3.4
CMJ PP (W)	3910 ± 318	3984 ± 555
CMJ PP (W/kg)†	50.3 ± 4.9	45.0 ± 3.1
CMJ height (cm)*	43.1 ± 4.1	39.9 ± 3.2
Sprint (s)†	3.11 ± 0.04	3.22 ± 0.09
COD (s)	2.58 ± 0.09	2.65 ± 0.11

HPC = hang power clean; PP = peak power; FS = front squat; CMJ = counter movement jump with 40-kg barbell; CMJ = counter movement jump without external load.

*$P < 0.05$.

†$P < 0.01$.

Table 2. Relationships between each measurement (Pearson's r).

	HPC 1RM	HPC 1RM/BM	FS 1RM	FS 1RM/BM	CMJ 40 PP	CMJ 40 PP/BM	CMJ PP	CMJ PP/BM	CMJ Height	Sprint	COD
HPC 1RM											
HPC 1RM/BM	0.68†										
FS 1RM	0.39*	0.25									
FS 1RM/BM	0.08	0.55†	0.70†								
CMJ 40 PP	0.58†	0.13	0.32†	−0.11							
CMJ 40 PP/BM	0.38*	0.60†	0.26	0.45*	0.63†						
CMJ PP	0.21	0.13	−0.15	−0.21	−0.01	−0.09					
CMJ PP/BM	0.30	0.58†	0.11	0.38	0.50†	0.92†	−0.26				
CMJ height	0.41*	0.51†	0.29	0.34	0.54†	0.75†	−0.12	0.81†			
Sprint	−0.58†	−0.57†	−0.60†	−0.51†	−0.49†	−0.62†	0.19	−0.58†	−0.69†		
COD	−0.41*	−0.34	−0.51†	−0.37*	−0.39*	−0.38*	−0.13	−0.27	−0.42*	0.52†	

HPC = hang power clean; /BM, relative to body mass; FS = front squat; CMJ 40, counter movement jump with 40-kg barbell; PP = peak power; CMJ = counter movement jump without the external load.
*$P < 0.05$.
†$P < 0.01$.

preferred foot just inside the starting line. The subject was instructed to start in his own time without any starting signal. Each subject performed the sprinting twice, and the better time was used for further statistical analysis. ICC obtained from the two repetitions was 0.80.

5–5 COD. Two lines (start line and 5-m line) were marked on the ground, 5-m apart (Figure 2). The pair of aforementioned timing gates was placed at the start line. The subject sprinted from the start line, then turned 180° on a line 5-m distant, and sprinted until the subject passed the start line again. The subject started as described for the 20-m sprint. When he turned, he was asked to either step on or step across the 5-m line. The time taken was obtained electronically from the timing gate system. This test was performed twice each with changing direction by right and left feet, and the best time of 4 trials (i.e., 2 of right foot and 2 of left foot) was used for statistical analysis. ICC obtained from the two best scores was 0.80.

Statistical Analyses

The subjects were divided into top half group (n = 14) and bottom half group (n = 14) based on 1RM hang power clean relative to the subject's body mass. The 1RM value relative to the subject's body mass was used because Baker and Nance (1) reported that the value relative to the body mass was more meaningful than the absolute value to examine the relationships between maximum strength, power and athletic performance. Since the present study had recruited an odd number of subjects, the middle of all 29 subjects was excluded from this statistical analysis (i.e., 1st to 14th subjects: top half group, 15th subject: excluded from this analysis, and 16th–29th subjects: bottom half group). The values obtained from each test were compared between these 2 groups with the use of one-way analyses of variance. The independent variable was group, and dependent variables were 1RM hang power clean (absolute value and value relative to the subjects' body mass), 1RM front squat (absolute value and value relative to the subjects' body mass), peak power in CMJ 40-kg and CMJ (absolute value and value relative to the subjects' body mass), jump height in CMJ (centimeters), time in 20-m sprint (seconds), and time in 5–5 COD (seconds). In addition, correlations between all measurements among all subjects were calculated by Pearson's product moment correlation coefficient (n = 29). The criterion for statistical significance was set at $P \leq 0.05$ for all analyses.

Results

The results for the different groups in the 1RM hang power clean relative to the subjects' body masses are shown in Table 1, and correlations between each measurement among all subjects are presented in Table 2. As can be observed from Table 1, the top half group exhibited significantly greater values than the bottom half group except for absolute peak power in CMJ and CMJ 40, and time in 5–5 COD. In addition, there were significant correlations found between most of, but not all combination of hang power clean performance and measurements of maximum strength, power, and jump, sprint, and COD performance (Table 2).

Discussion

In this study, we attempted to reveal whether an athlete who possesses higher performance in hang power clean perform better in jumping, sprinting, and COD than athlete who possesses lower performance in this exercise. To gain a better understanding, we also examined whether there were any underlying strength qualities that were common to the hang power clean and jumping, sprinting and COD. The major outcome was that the top half group in the 1RM hang power clean relative to the subjects' body mass had higher performance of jumping and sprinting, and demonstrated higher maximum strength measured by the 1RM front squat (both absolute and relative to the subject's body mass) and higher power measured by peak power output in the CMJ 40 (relative to the subject's body mass) and CMJ (relative to the subject's body mass). Thus, it seems that the individual who can perform well in the 1RM hang power clean possesses high maximum strength and power that is essential for peak performance of jumping and sprinting. One RM hang power clean relative to the subject's body mass, 1RM front squat relative to the subject's body mass, power output relative to the subject's body mass in CMJ 40 and CMJ, jump height in CMJ, and time in the 20-m sprint were significantly correlated each other ($r = 0.51–0.60$). From these significant correlations, it seems reasonable to assume that the 1RM hang power clean was sharing similar strength qualities required for jumping and sprinting. Previous studies (27,32) have reported the ability to apply high force and power in the vertical direction is related to performance of sprinting, so that it has been suggested that the activity exerting high force and power rapidly in vertical direction such as the weightlifting exercises would help to develop sprint performance (1,34). Also, the present study is in agreement with the previous studies (3,28) reporting that the subject who can exhibit higher 1RM in the weightlifting exercises was able to jump higher and exert higher power output during vertical jump movement.

However, there was no significant difference in performance of 5–5 COD between the groups. Interestingly, there was no significant correlation between the 5–5 COD time and the 1RM hang power clean relative to the subject's body mass ($r = -0.34$), but there was a significant correlation between the 5–5 COD time and the absolute value of 1RM hang power clean ($r = -0.41$). It was hypothesized that the value relative to the subject's body mass would be more related to the 5–5 COD performance than the absolute value (1), and we cannot propose any explanation of this unexpected result. In our opinion, the 5–5 COD can be divided into 2 phases: (1) start line to 5-m line, and (2) 5-m line to start line. The ability to accelerate quickly at the start line is an important part of 5–5 COD. However, when the athlete changes his direction, the higher the velocity before the COD, the greater is the momentum that he needs to overcome. Perhaps it is counterproductive if the athlete accelerates his velocity more than necessary prior to the COD. Therefore, it is speculated that the optimal decision making about how much the athlete accelerates his velocity and when he starts to decelerate during the first 5 m is the other factor determining the performance of 5–5 COD. The 1RM front squat (both absolute and body mass relative) and CMJ 40 power (both absolute and body weight relative) were significantly correlated with 5–5 COD ($r = 0.37–0.51$), so that maximum strength and power are still factors contributing the performance of 5–5 COD. However, it appears likely that other factors influence COD performance such as the ability of optimal decision making. Possibly, it may be the reason why the present study did not show any significant difference between 5–5 COD time in the two groups. Further, the importance of the ability to accelerate/decelerate his velocity in performance of COD may be varied dependent on the pattern of running such as distance of sprint and angle of COD (22,35,36).

Although the present study found that the performance of 1RM hang power clean could differentiate performance of jumping and sprinting, the design used in the present study could not explain the cause and effect. For practitioners, it is important to consider if the training of weightlifting exercises (e.g., hang power clean) would improve the performance of jumping, sprinting and COD. At present, only 3 training studies (18,28,31) have investigated the effects of training with weightlifting exercises on the performance of jumping, sprinting and/or COD. Stone et al. (28) reported that 14 weeks training with weightlifting exercises improved jump performance significantly. However, this study did not examine the effects of weightlifting exercises on sprinting and COD performance. Hoffman et al. (18) compared the effects of 15 weeks of weightlifting exercises versus powerlifting exercises (i.e., squat, bench press, and deadlift) on jumping, sprinting, and COD performance, and reported the efficacy of weightlifting exercises on jumping performance. However, this study had limitations in their measurements of performance. For example, the pretest values of sprint and COD were taken during preseason of the previous year, which was several months before when the training intervention started. In this manner, the effects of weightlifting exercises on sprint and COD might not have been assessed appropriately. Tricoli et al. (31) have reported that the improvement in jumping and sprinting performance was larger for a weightlifting group compared with a vertical jump training group after an 8-week training intervention performed 3 times a week. However, the study used physical education students as subjects who had no lower-body strength training for three months prior to the investigation. Therefore, it is questionable if the findings from this study can be applied to athletes, particularly those who already have an extensive resistance training background. As a future direction, it is warranted further investigation involving well controlled training interventions overcome the weakness of previous training studies (18,28,31).

In conclusion, the present study found that the group possessing the greater 1RM hang power clean relative to the body mass also possessed higher maximum strength, power and performance of jumping and sprinting. However, the 1RM hang power clean relative to the subject's body mass could not differentiate the good and poor performance of

COD. There were significant correlations between the 1RM hang power clean relative to the subject's body mass, maximum strength, power and performance of jumping and sprinting, but there was no correlation between the 1RM hang power clean relative to the subject's body mass and COD although there were significant correlations between absolute value and the performance of COD.

Practical Applications

From the results of this study, it may be speculated the training of the weightlifting exercises such as the hang power clean may be effective to improve the athlete's capability of power, and subsequently athletic performance which requires high power for skills such as jumping, sprinting. However, there was no significant difference between the 5–5 COD time of top and bottom half groups in the 1RM hang power clean relative to the subject's body mass, and the correlation coefficient between the 1RM hang power clean (both absolute and relative to body mass) and jumping, sprinting, and COD ($r = 0.37–0.58$) implied that there was a large amount of variance that the 1RM hang power clean could not explain. From the findings of the present study, practitioners may incorporate the weightlifting exercises into their programs, but it is also recommended to take a holistic approach to improve jump, sprint and COD performance which includes skill practice in addition to development of maximum strength and power.

In addition to the findings discussed, the present study also suggests that 1RM hang power clean may be a good benchmark test of strength and power. In general, practitioners cannot conduct the performance measurement test as frequently as they want because of a number of uncontrollable reasons. For example, sport teams located in cold environments cannot conduct sprint performance tests outdoors during the winter. Further, unless sufficient testing equipment (e.g., force plate, jump and reach, or timing gates) are available, it is very difficult to test large numbers of athletes at once. Thus, practitioners often encounter problems of scheduling especially during the in-season. Practitioners working in these circumstances may consider the 1RM hang power clean as a convenient way to assess the athletes' neuromuscular performance instead of actual measurement of jumping height or sprinting time since the hang power clean can be performed as a part of regular training. Particularly when the training program is in high intensity and low volume phase, typically used in-season, experienced practitioners could easily estimate their athletes' 1RM even if their 1RM were not actually measured. The hang power clean appears to provide a useful summary measure to track athlete strength and power for monitoring progression and training program effectiveness as well as possible declines attributed to injury, illness, or overtraining.

References

1. Baker, D and Nance, S. The relation between running speed and measures of strength and power in professional rugby league players. *J Strength Cond Res* 13: 230–235, 1999.
2. Canavan, PK, Garrett, GE, and Armstrong, LE. Kinematic and kinetic relationships between an Olympic-style lift and the vertical jump. *J Strength Cond Res* 10: 127–130, 1996.
3. Carlock, JM, Smith, SL, Hartman, MJ, Morris, RT, Ciroslan, DA, Pierce, KC, Newton, RU, Harman, EA, Sands, WA, and Stone, MH. The relationship between vertical jump power estimates and weightlifting ability: a field-test approach. *J Strength Cond Res* 18: 534–539, 2004.
4. Chiu, LZF and Schilling, BK. A primer, or weightlifting: From sport to sports training. *Strength Cond J* 27: 42–48, 2005.
5. Cronin, J and Sleivert, G. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Med* 35: 213–234, 2005.
6. Cronin, JB and Hansen, KT. Strength and power predictors of sports speed. *J Strength Cond Res* 19: 349–357, 2005.
7. Dugan, E, Doyle, TLA, Humphries, B, Hasson, CJ, and Newton, RU. Determining the optimal load for jump squats: A review of methods and calculations. *J Strength Cond Res* 18: 668–674, 2004.
8. Ebben, WP and Blackard, DO. Strength and conditioning practice of National Football League strength and conditioning coaches. *J Strength Cond Res* 15: 48–58, 2001.
9. Ebben, WP, Carroll, RM, and Simenz, C. Strength and conditioning practice of National Hockey League strength and conditioning coaches. *J Strength Cond Res* 18: 889–897, 2004.
10. Enoka, RM. *Neuromechanical Basis of Kinesiology* (2nd ed.). Champaign, IL: Human Kinetics, 1994.
11. Fry, AC and Kraemer, WJ. Physical performance characteristics of American collegiate football players. *J Appl Sports Sci Res* 5: 126–138, 1991.
12. Fry, AC, Kraemer, WJ, Weseman, CA, Conroy, BP, Gordon, SE, Hoffman, JR, and Maresh, CA. The effects of an off-season strength and conditioning program on starters and non-starters in women's intercollegiate volleyball. *J Strength Cond Res* 5: 174–181, 1991.
13. Garhammer, J and Gregor, R. Propulsion force as a function of intensity for weightlifting and vertical jumping. *J Appl Sports Sci Res* 6: 129–134, 1992.
14. Garhammer, J. A review of power output studies of Olympic and powerlifting: methodology, performance prediction, and evaluation tests. *J Strength Cond Res* 7: 76–89, 1993.
15. Haff, GG, Stone, M, O'Bryant, HS, Harman, E, Dian, C, Johnson, R, and Han, K-H. Force-time dependent characteristics of dynamic and isometric muscle actions. *J Strength Cond Res* 11: 269–272, 1997.
16. Harris, GR, Stone, MH, O'Bryant, HS, Proulx, CM, and Johnson, RL. Short-term performance effects of high power, high force, or combined weight-training methods. *J Strength Cond Res* 14:14–20, 2000.
17. Hoffman, JR. Relationship between athletic performance tests and playing time in elite college basketball players. *J Strength Cond Res* 10: 67–71, 1996.
18. Hoffman, JR, Cooper, J, Wendell, M, and Kang, J. Comparison of Olympic vs. traditional power lifting training programs in football players. *J Strength Cond Res* 18: 129–135, 2004.
19. Hori, N, Newton, RU, Nosaka, K, and Stone, MH. Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength Cond J* 27: 50–55, 2005.
20. Hori, N, Newton, RU, Nosaka, K, and McGuigan, MR. Comparison of different methods of determining power output in weightlifting exercises. *Strength Cond J* 28: 34–40, 2006.
21. Kawamori, N, Crum, AJ, Blumert, PA, Kulik, JR, Childers, JT, Wood, JA, Stone, MH, and Haff, GG. Influence of different relative intensities on power output during the hang power clean: identification of the optimal load. *J Strength Cond Res* 19: 698–708, 2005.
22. Little, T and Williams, A. Specificity of acceleration, maximum speed, and agility in professional soccer players. *J Strength Cond Res* 19: 76–78, 2005.

23. Newton, RU and Kraemer, WJ. Developing explosive muscular power: Implications for a mixed methods training strategy. *Strength Cond* 16:20–31. 1994.
24. Plisk, S and Stone, MH. Periodization strategies. *Strength Cond J* 17: 19–37, 2003.
25. Schmidtbleicher, D. Training for power events. In: *Strength and Power in Sport.* Komi PV, ed. Oxford: Blackwell Scientific Publications, 1992, pp. 381–395.
26. Simenz, CJ, Dugan, CA, and Ebben, WP. Strength and conditioning practice of National Basketball Association strength and conditioning coaches. *J Strength Cond Res* 19: 495–504, 2005.
27. Sleivert, G and Taingahue, M. The relationship between maximal jump-squat power and sprint acceleration in athletes. *Eur J Appl Physiol* 91: 46–52, 2004.
28. Stone, MH, Byrd, R, Tew, J, and Wood, M. Relationship between anaerobic power and Olympic weightlifting performance. *J Sports Med* 20:99–102, 1980.
29. Stone, MH, O'Bryant, HS, McCoy, L, Coglianese, R, Lehmkuhl, M, and Schilling, B. Power and maximum strength relationships during performance of dynamic and static weight jumps. *J Strength Cond Res* 17: 140–147, 2003.
30. Stone, MH, Sanborn, K, O'Bryant, HS, Hartman, M, Stone, ME, Proulx, C, Ward, B, and Hruby, J. Maximum strength-power-performance relationships in college throwers. *J Strength Cond Res* 17: 739–745, 2003.
31. Tricoli, V, Lamas, L, Carnevale, R, and Ugrinowitsch, C. Short-term effects on lower-body functional power development: Weightlifting vs. vertical jump training programs. *J Strength Cond Res* 19: 433–437, 2005.
32. Weyand, PG, Sternlight, DB, Bellizzi, MJ, and Wright, S. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *J Appl Physiol* 89: 1991–1999, 2000.
33. Wilson, GJ, Newton, RU, Murphy, AJ, and Humphries, BJ. The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc* 25:1279–1286, 1993.
34. Young, W, Benton, D, Duthie, G, and Pryor, J. Resistance training for short sprints and maximum-speed sprints. *Strength Cond J* 23:7–13, 2001.
35. Young, WB, McDowell, MH, and Scarlett, BJ. Specificity of sprint and agility training methods. *J Strength Cond Res* 15:315–319, 2001.
36. Young, WB, James, R, and Montgomery, I. Is muscle power related to running speed with changes of direction? *J Sports Med Phys Fitness* 42: 282–288, 2002.
37. Young, WB, Newton, RU, Doyle, TL, Chapman, D, Cormack, S, Stewart, G, and Dawson, B. Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian Rules football: a case study. *J Sci Med Sport* 8:333–345, 2005.