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A Comparison of Strength and Power Characteristics Between Power Lifters, Olympic Lifters, and Sprinters

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ABSTRACT

The purpose of this investigation was to determine the effect of involvement in power lifting, Olympic lifting, and sprinting on strength and power characteristics in the squat movement. A standard one repetition maximum squat test, jump squat tests, and vertical jumps with various loads were performed. The power lifters (PL, $n = 8$), Olympic lifters (OL, $n = 6$), and sprinters (S, $n = 6$) were significantly stronger than the controls (C, $n = 8$) ($p \leq 0.05$). In addition, the OL group was significantly stronger than the S group. The OL group produced significantly higher peak forces, power outputs, velocities, and jump heights in comparison to the PL and C groups for jump trials at various loads. The S group produced higher peak velocities and jump heights in comparison to the PL and C groups for jump trials at various loads. The PL group was significantly higher in peak force and peak power for jump trials at various loads in comparison to the C group. The data indicates that strength and power characteristics are specific to each group and are most likely influenced by the various training protocols utilized.

Key Words: squats, training, performance, jumping, specificity

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Introduction

A simple definition of maximal power as stated by Häkkinen and Komi (10) is the explosive nature of force production. Maximal power has been marked as being synonymous with explosive strength. While strength is related to power, its definition is quite different. Strength is maximal force production. High power output effort by muscle is characterized by brief muscle actions and high movement velocities (25). Many sports involve movements that require the generation of force over a short period of time. These movements include jumping and sprinting and may be improved by specific increases in muscular power rather than overall strength (29). Therefore, it may be necessary to develop resistance-training programs that increase both power and strength. However, debate continues as to what combination of loading, movement velocities, power outputs, and exercises should be used in resistance training to optimize the development of muscle power and physical performance (2, 10, 11, 14, 18, 19, 22, 29). Cross-sectional analysis of groups known to perform specific types of training over a period of several years may provide some direction in this area.

Training Characteristics

Power lifters are known to focus on maximal force production, slow velocity lifts. The initiation of the movement is explosive, but the ensuing movement is at a slow velocity due to the load and the biomechanics of the lifts involved (5, 8, 24). It is known that Olympic lifters use both standard resistance exercise techniques, which include heavy load, slow velocity movements and explosive type lifts such as the snatch and clean and jerk in their training (16). These lifts allow for the use of heavy loads and high velocities simultaneously, thus producing high power outputs (7, 8). In contrast, sprinters focus primarily on their event, which would be characterized by low-resistance, explosive, high-velocity movements (e.g., sprinting) (23).

Muscle Strength and Power

Power lifters have been previously shown to be not as strong or powerful as Olympic lifters (12). This was based on strength-to-body weight ratios and time to peak isometric force production measurements (12). Improvement in both rate of force development and maximal force production has been reported in Olym-

Table 1. Subject characteristics.

Variable	Power lifters	Olympic lifters	Sprinters	Controls
Age (y)	24.1 ± 1.2*†	20.2 ± 1.1	19.8 ± 0.8	22.3 ± 0.8
Height (cm)	173.9 ± 1.4*	172.0 ± 2.9‡§	182.1 ± 1.7	181.1 ± 1.9
Weight (kg)	78.2 ± 3.7	85.3 ± 9.5	76.9 ± 2.6	75.6 ± 3.3
Body fat (%)	8.7 ± 1.3	10.4 ± 2.8	5.6 ± 0.2	9.5 ± 1.6
Years of training	4.8 ± 1.1	3.1 ± 0.8	3.8 ± 0.6	—

* Significant difference between the PL group and the S group.
† Significant difference between the PL group and the C group.
‡ Significant difference between OL and S group.
§ Significant difference between the OL group and the C group.

pic lifters over a year of training (16). These findings suggest that the type of training used by Olympic lifters may be effective in increasing muscle strength and power concurrently (15). The type of training used by sprinters has been shown to result in smaller strength gains than the methods employed by Olympic and power lifters (9). However, this explosive, low-resistance type of training adopted by sprinters has been shown to have a dramatic effect on rate of force development (9). This observation of the force–time curve suggests a more powerful muscle, i.e., a muscle able to generate a given amount of force in a very short period of time.

The purpose of this investigation was to compare groups of athletes known to perform distinct styles of training in order to compare three protocols of exercise: high force, slow velocity; high force, high velocity; and low force, high velocity. It was hypothesized that a profile of both strength and power characteristics may exist for the power lifters (high force, slow velocity), Olympic lifters (high force, high velocity), and sprinters (low force, high velocity) in this investigation. Therefore, the analysis of these three groups who are known to perform specific types of training over many years may give some preliminary information as to the effect of that training on muscle strength, power, and physical performance.

Methods

Subjects. This study involved a total of 28 male subjects between the ages of 18 and 32. All subjects with the treatment groups were given a questionnaire concerning their competitive status. Subjects were chosen for the three treatment groups based on being competitive at the national level. This included subjects that had placed either first or second in a major state event or a minimum of fifth in a national level competition for their specific discipline. Each group had an equal distribution of subjects from the guidelines specified above. This means that the groups were compared equally in terms of the success each group had accomplished in their specific sport. The control group consisted of moderately active individuals with no current or prior experience of any kind with resistance training. Table 1 indicates the number of years training for each group. These numbers indicate the number of years that they have been actively training and competing in their respective sport. Due to some variation in the number of years of active competition, each subject was asked to outline via a questionnaire a minimum of the past 3 years and a maximum of the past 5 years with regard to their training protocols. They were then asked to outline in specific detail their training protocols used for the previous 6 months. After review of each subject's response to this training questionnaire, it was ensured that at least 75% of their training was specific to the group in which they were classified. This means that each group had a significant training stimulus that the other group did not have. All groups contained subjects that were not currently (or in the previous year) taking anabolic steroids, growth hormone, or related performance-enhancement drugs of any kind. All three organizations in which the power lifters, Olympic lifters, and sprinters competed were drug-free organizations with randomized urinalysis testing for all athletes. Subjects were not eliminated if taking vitamins, minerals, or other related natural supplements. Each subject was required to fill out a medical history questionnaire (which was, if needed, screened by a physician) to eliminate individuals with contraindications for participating in this investigation. Prior approval by the Human Experimentation Ethics Committee of Southern Cross University was obtained for this experiment. All subjects were informed of any risks associated with participation in this study and asked to sign an informed consent document prior to any testing.

Study Design. This study consisted of four groups: power lifters (PL), Olympic lifters (OL), sprinters (S), and controls (C) (Table 1). All of the testing for a given subject was completed on a single day. Vertical jump testing was completed first, followed by a one repetition maximum (1RM) test and then jump squats with

30, 60, and 90% of the 1RM with a recovery period of 10 minutes between each of the three tests. Subjects were allowed self-selection in their stance and body positions for all of the tests due to their extensive training experience in their respective disciplines. However, the stance and bar position determined by the subject for the squat testing were required to fit within the following specified criteria and were kept consistent for all the testing. Bar placement on the back for each subject was required to be between the superior portion of the scapula and vertebra C-7. The stance for each subject was constrained to within 15 cm of the lateral portion of that individual's deltoid. Outward positioning of the toes of up to 30° was allowed. The distance between the heels of the feet and the bar was required to be no more than 8 cm (either in front of or behind the bar). No stance criteria was established for the vertical jump tests. The various loads used in the vertical jump testing were randomized. The jump squats were performed as 30, 60, and 90% loads, respectively, for each subject. The best trial for each load and jump combination was used for comparisons based on adherence to proper form and maximal jump height.

Body Composition. Skinfold measurements were obtained with Harpenden skinfold calipers (Mentone Educational Centre, Carnegie, Victoria, Australia; accuracy, ±0.1 mm), which measured the amount of subcutaneous fat at various anatomical sites on the chest, thigh, and abdomen. From the skinfold measurements, an estimate of percent body fat was determined (17). Height (Handy Height Scale, Mentone Educational Centre; accuracy, ±0.1 cm) and weight (ID2 Multi Range Scale, Mettler, Greifensee, Switzerland; accuracy, ±0.01 kg) were also recorded for each subject.

Vertical Jump Testing. A counter movement jump (CMJ) was performed for this test. Two warm-up trial jumps were performed using body weight. The subjects then completed the test jumps, in a randomized order, with body weight and additional 20 and 40 kg loading achieved by holding dumbbells in each hand. The CMJ was performed by each subject first standing erect. A quick downward counter movement with limited arm movement was allowed prior to attempting to jump to a maximum height. This downward counter movement was executed to a knee angle of 90° and was visually monitored for each trial. One minute of rest was allowed between each jump and 2 minutes of rest was allowed between each load condition. Three trials were performed for the CMJ at each given load.

One Repetition Maximum Testing. This test was modified slightly from established protocols previously described (27). This test was performed in a Smith machine as described previously by Wilson et al. (29). A number of warm-up trials were given in the 1RM test protocol using 30 (8–10 repetitions), 50 (4–6 repetitions), 70 (2–4 repetitions), and 90% (one repetition) of an estimated 1RM either from the subjects recommendation or 2–2.5 times the subject's body weight. From this point, the weights were increased to a point where the individual had 3–4 maximal efforts to determine the 1RM for the Smith machine squat exercise. Each subject was asked to lower the bar to the point where the knee angle was 90°. They were told that, when they reached the bottom portion of the movement, which was marked by an audible cue and adjustable stoppers, to immediately move the weight upward in a controlled but forceful fashion to the starting position. Adequate rest was allowed between trials (3–5 minutes).

30, 60, and 90% of 1RM Trials. This testing involved performing a jump squat (JS) in a Smith machine as described previously by Wilson et al. (29). Two warm-up trial jumps, with only the bar, were completed. The value of approximately 30% of each subject's 1RM was used. It has been shown that the maximal mechanical power output occurs using loads within this range (19, 25). The 60 and 90% loads were considered moderate and heavy training loads. Performance of the jump squat involved lowering the bar to the point where the knee angle was 90°. Subjects were instructed that, when they reached they bottom portion of the movement, which was marked by an audible cue and adjustable stoppers, to immediately jump and explode upward as fast as possible with their feet leaving the floor. Two minutes of rest was allowed between jumps and 3 minutes was allowed between load conditions. Two trials were performed for the jump squat at each given load.

Biomechanical Analyses. Vertical ground reaction forces (VGFR) during the vertical jumps were recorded using a force plate (Kistler type 9287, Kistler Instruments Corporation, Amherst, NY) mounted below the subject's feet. Standard biomechanical analyses were performed using a custom-designed computer program written in Visual Basic (Microsoft Corporation, Redmond, WA) to determine peak force, peak velocity, peak power output, and jump height. The intraclass correlation coefficients (ICC) for the calculation of these variables as it relates to the vertical jump testing are 0.927, 0.951, 0.998, and 0.947, respectively. VGFRs during the jump squats were also recorded using a force plate (Kistler type 9287) mounted below the subject's feet and a position transducer (IDM Instruments, Dandenong, Victoria, Australia; accuracy, ±0.1 cm) attached to the bar to record bar displacement. The force and displacement measurements were used to determine peak force, peak velocity, peak power output, and jump height again, using the custom-designed computer program. The ICC for the calculation of these variables as it relates to the jump squat testing are 0.963, 0.775, 0.690, and 0.918, respectively.

Statistical Analyses. Subject characteristics were analyzed using an ANOVA with Bonferroni post hoc tests. Squat strength trials were analyzed using a general factorial model with body weight as a covariate with simple and repeated contrast group comparisons. All jump analyses involved the use of a MANOVA with body weight as a covariate with simple and repeated contrast group comparisons. Peak force, peak velocity, peak power, and jump height were analyzed in combination for each type of jump and load condition. After running a correlation matrix, it was found that body weight had a significant linear relationship to all of the variables measured concerning strength and power in each group. Therefore, body weight was an ideal covariate, as it was not affected by the independent variable but had a significant relationship to the specified dependent variables. Body weight was used as a covariate to ensure comparisons were based on the grouping characteristic factor only. Body weight-to-performance ratios were not used because of the possible differences in the upper and lower body weight distributions between the three groups (12). The results are presented as adjusted means and standard errors according to the covariate body weight analyses. As an estimate of effect size, $\eta^2 = 0.552$ at an observed power level of 0.991 for squat strength. In addition, $\eta^2 = 0.405$ at an observed power level of 0.876 for the peak power measurement in the 30% load jump squat. The α level was chosen at $p \leq 0.05$. All statistical analyses were performed by a statistical software package (SPSS, Version 7.5, SPSS Inc., Chicago, IL).

Results

Subject Characteristics

The PL group was significantly older than the S and C groups. The S group was significantly taller than the PL and OL groups. The C group was significantly taller than the OL group. No significant differences existed in weight, percentage body fat, or years of training between the groups.

Smith Machine Squat Strength

Squat strength in the Smith machine squat exercise to a knee angle of 90° was significantly different between the groups (Figure 1). The PL (225.5 ± 10.8 kg), OL (243.9 ± 12.8 kg), and S (204.3 ± 12.5 kg) groups were significantly higher in squat strength than the C group (161.3 ± 10.9 kg). The OL group was significantly higher in squat strength than the S group.

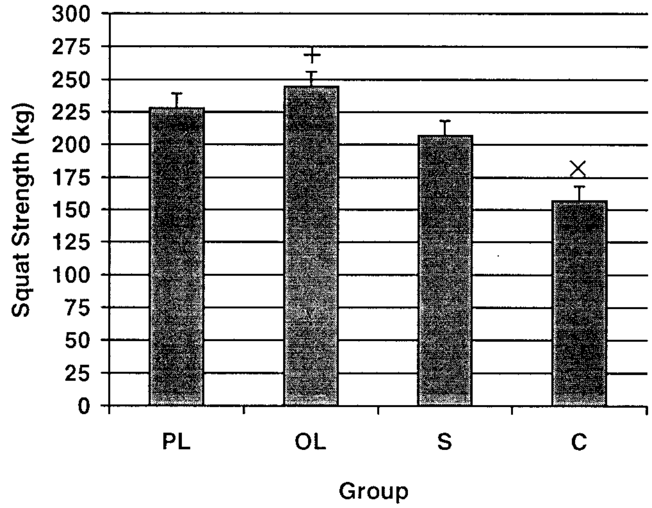

Figure 1. Maximal leg strength in a Smith machine squat to a knee angle of 90°. Values are adjusted means and standard errors based on MANOVA with body weight as a covariate. +, significant difference between the OL group and the S group; ×, significant difference between the C group and the PL, OL, and S groups. Significance level at $p \leq 0.05$.

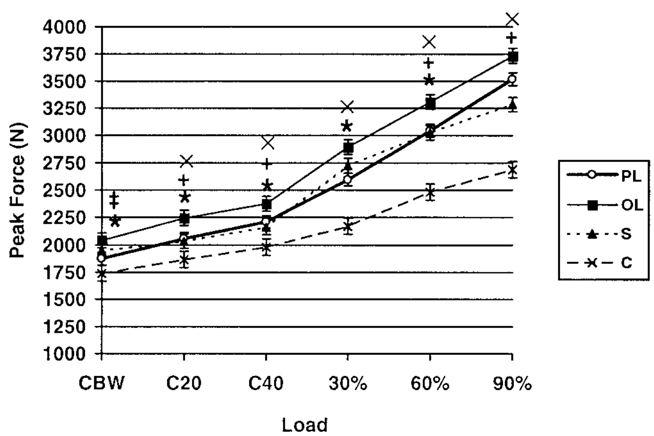

Figure 2. Peak force at various loads in the CMJ and JS. Values are adjusted means and standard errors based on MANOVA with body weight as a covariate. *, significant difference between the PL group and the OL group; ‡, significant difference between the C group and the OL and S groups. Significance level at $p \leq 0.05$.

Countermovement Vertical Jumps

Peak force in the CMJ was significantly higher in the OL and S groups in comparison to the C group for all three load conditions (Figure 2, Table 2). Peak force in the CMJ was significantly higher in the PL group in comparison to the C group for the 20- and 40-kg load conditions. Peak force in the CMJ was significantly different between the OL and PL groups for the body weight load condition. Peak force was significantly higher for the OL group in comparison to both the PL and S groups for the 20- and 40-kg load conditions. Peak velocity for the OL and S groups was significantly higher than for the C and PL groups for all the load conditions (Figure 3, Table 2). Peak velocity for the PL group was significantly higher than for the C group in the 40-kg load condition only. Peak power was significantly higher in the PL, OL, and S groups in comparison to the C group for all the load conditions (Figure 4, Table 2). Peak power was significantly higher in the OL group in comparison to the PL group

Table 2. Countermovement vertical jumps (mean ± *SD*).*

Variable	Power lifters	Olympic lifters	Sprinters	Controls
CBW				
Peak force (N)	1,854.2 ± 49.4	2,022.9 ± 58.8	1,924.9 ± 57.2	1,741.0 ± 49.8
Peak velocity ($m\cdot s^{-1}$)	2.86 ± 0.07	3.18 ± 0.08	3.17 ± 0.08	2.68 ± 0.07
Peak power (W)	4,447.1 ± 192.0	5,377.8 ± 228.2	4,906.2 ± 222.1	3,737.7 ± 193.6
Jump height (cm)	39.7 ± 2.3	48.2 ± 2.8	49.9 ± 2.7	33.7 ± 2.3
C20				
Peak force (N)	2,036.1 ± 42.3	2,226.0 ± 50.3	2,012.9 ± 48.9	1,867.8 ± 42.7
Peak velocity ($m\cdot s^{-1}$)	2.55 ± 0.06	2.89 ± 0.07	2.83 ± 0.07	2.41 ± 0.06
Peak power (W)	4,452.4 ± 146.1	5,386.4 ± 173.7	4,809.3 ± 169.1	3,789.6 ± 147.4
Jump height (cm)	30.4 ± 1.4	35.6 ± 1.7	36.5 ± 1.7	25.8 ± 1.5
C40				
Peak force (N)	2,190.8 ± 34.0	2,357.0 ± 40.4	2,140.7 ± 39.3	1,981.4 ± 34.3
Peak velocity ($m\cdot s^{-1}$)	2.25 ± 0.05	2.48 ± 0.06	2.51 ± 0.06	2.10 ± 0.05
Peak power (W)	4,301.0 ± 144.9	5,050.0 ± 172.3	4,747.4 ± 167.6	3,631.7 ± 146.1
Jump height (cm)	22.1 ± 1.1	26.4 ± 1.3	27.3 ± 1.3	18.2 ± 1.1

* Significant differences are indicated in Figures 2, 3, 4, and 5.

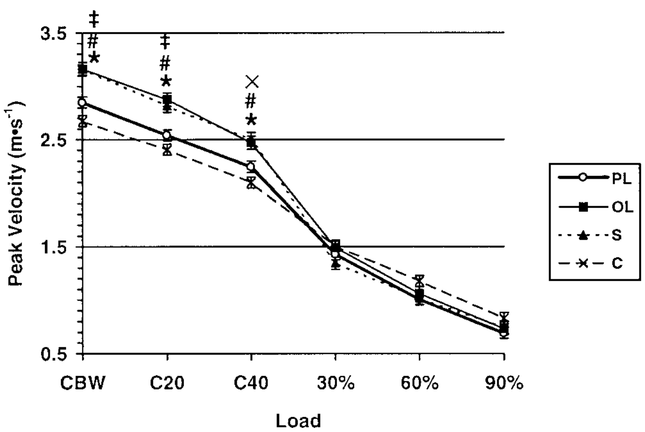

Figure 3. Peak velocity at various loads in the CMJ and JS. Values are adjusted means and standard errors based on MANOVA with body weight as a covariate. #, significant difference between the PL group and the S group. Significance level at $p \leq 0.05$.

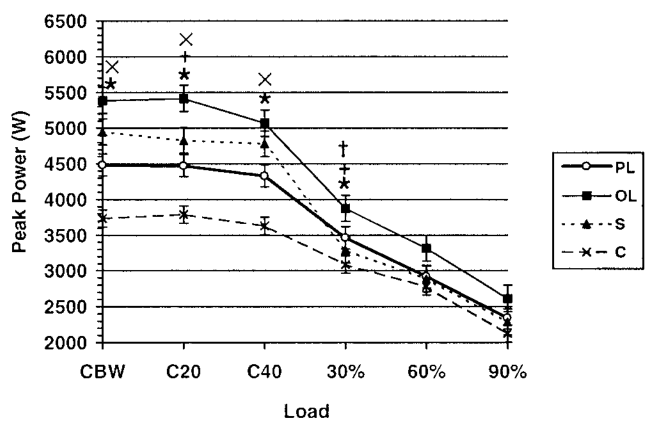

Figure 4. Peak power at various loads in the CMJ and JS. Values are adjusted means and standard errors based on MANOVA with body weight as a covariate. †, significant difference between the OL group and the C group. Significance level at $p \leq 0.05$.

for all the load conditions. In addition, peak power was significantly higher in the OL group in comparison to the S group in the 20-kg load condition. Jump height was significantly higher in the OL and S groups in comparison to the PL and C groups for all three load conditions (Figure 5, Table 2). Jump height was significantly higher in the PL group in comparison to the C group in the 20- and 40-kg load conditions.

Jump Squats

Peak force was significantly higher in the PL, OL, and S groups in comparison to the C group for all three load conditions (Figure 2, Table 3). Peak force was significantly higher in the OL group in comparison to the PL group in the 30 and 60% load conditions and to the S group in the 60 and 90% load conditions. Peak velocity was not significantly different between the PL, OL, S, and C groups for any of the load conditions (Figure 3, Table 3). Peak power was significantly higher in the OL group in comparison to the PL, S, and C groups in the 30% load condition (Figure 4, Table 3). Jump height was significantly higher in the S group in comparison to the PL, OL, and C groups in the 30% load condition (Figure 5, Table 3). Jump height was significantly higher in the OL, S, and C group in comparison to the PL group in the 60% load condition. Jump height was significantly higher in the S group in comparison to the PL and OL groups in the 90% load condition. Jump height was significantly higher in the C group in comparison to the PL group in the 90% load condition.

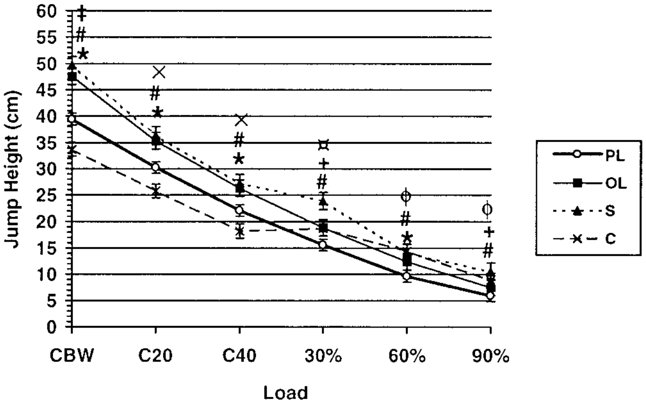

Figure 5. Jump height at various loads in the CMJ and JS. Values are adjusted means and standard errors based on MANOVA with body weight as a covariate. ¤, significant difference between the S group and the C group; ϕ, significant difference between the PL group and the C group. Significance level at $p \leq 0.05$.

Discussion

The primary finding in this investigation is that noticeable differences exist in strength, power, and related physical performance measurements between power lifters, Olympic lifters, sprinters, and moderately active controls. The PL group was as strong as the OL and S groups but scored significantly lower in tests for power and explosive performance. This included lower peak power outputs, peak velocities, and jump heights. In some instances, the PL group even performed worse than the C group in relation to these variables. The OL group was comparable in strength to the PL group, was stronger than the S group, and was also the most powerful of all the groups. The OL group also scored well in physical performance as determined by vertical jump height. The S group was not as powerful as expected but was able to generate high peak velocities and some of the highest recorded jump heights.

The PL, OL, and S groups produced significantly higher levels of leg strength in comparison to the C group, as would be expected. This is due to the documented effects of resistance training in increasing muscular strength (20, 21, 26). In addition, the similarity in leg strength between the OL and PL groups is not unexpected, based on the necessity of leg strength for competition in both events. However, the lack of significant difference between the PL and S groups was surprising. It is acknowledged that the PL group may have been disadvantaged due to the inability of the power lifters to utilize the lower back and hip joint in the Smith machine squat, which is common in a typical power lifting free weight squat (30). However, this test was designed to isolate and measure the maximal strength of the legs only and was consistent over all the groups. This pattern of strength between the PL and OL groups is supported by a previous investigation involving Olympic lifters, power lifters, and body builders (12). However, the lack of significant difference in leg strength between sprinters and power lifters is not consistent with previous literature. Power lifters and Olympic lifters have previously been shown to be stronger than sprinters (9). It is possible that previous investigations involved subjects with greater variability in body weight than in this investigation. This variability and perhaps variability in strength-to-body weight ratios may result in inaccuracies when trying to determine strength levels between different types of athletes. It is also noted that

Table 3. Jump squats (mean ± *SD*).

Variable	Power lifters	Olympic lifters	Sprinters	Controls
JS30				
Peak force (N)	2,565.8 ± 55.9	2,874.4 ± 66.5	2,692.0 ± 64.7	2,170.5 ± 56.4
Peak velocity ($m \cdot s^{-1}$)	1.43 ± 0.05	1.49 ± 0.06	1.35 ± 0.06	1.50 ± 0.05
Peak power (W)	3,426.2 ± 126.7	3,857.1 ± 150.6	3,249.1 ± 146.5	3,087.6 ± 127.7
Jump height (cm)	15.6 ± 1.4	18.9 ± 1.7	23.9 ± 1.6	18.7 ± 1.4
JS60				
Peak force (N)	3,010.3 ± 84.1	3,287.7 ± 100.0	2,986.8 ± 97.3	2,482.6 ± 84.8
Peak velocity ($m \cdot s^{-1}$)	1.01 ± 0.05	1.06 ± 0.05	1.02 ± 0.05	1.18 ± 0.05
Peak power (W)	2,888.3 ± 137.7	3,297.8 ± 163.8	2,848.6 ± 159.4	2,780.8 ± 138.9
Jump height (cm)	9.7 ± 0.8	12.4 ± 1.0	14.1 ± 0.9	14.4 ± 0.8
JS90				
Peak force (N)	3,478.5 ± 100.2	3,717.3 ± 119.2	3.240.2 ± 116.0	2,687.9 ± 101.1
Peak velocity ($m \cdot s^{-1}$)	0.69 ± 0.04	0.73 ± 0.05	0.75 ± 0.05	0.83 ± 0.04
Peak power (W)	2,324.2 ± 133.4	2,595.0 ± 158.6	2,266.1 ± 154.3	2,127.6 ± 134.5
Jump height (cm)	6.0 ± 0.9	7.4 ± 1.0	10.6 ± 1.0	8.9 ± 0.9

* Significant differences are indicated in Figures 2, 3, 4, and 5.

the S group in this investigation reported an unexpectedly high frequency of strength-related resistance training.

The CMJ provided an abundance of the group-defining characteristics. The OL and S groups consistently outperformed the C group in peak force, peak velocity, peak power, and jump height. However, the PL group tended to perform better than the C group only in the 20- and 40-kg load conditions with the exception of peak power output. The OL group had significantly higher peak forces than either the PL or S groups. In addition, the OL group had significantly higher peak velocities, peak power outputs, and jump heights in comparison to the PL group. These patterns are supported by a previous investigation involving loaded vertical jump and rate of force development tests (12). The S group achieved some of the highest recorded vertical jump heights. However, they did not show significantly greater force outputs or power outputs than either the OL or PL groups. Peak velocity was consistently higher for the S group in comparison to the PL group, as was jump height for all of the load conditions. The efficiency of the S group in producing high velocity movements has been reported (23). The poor performance of the PL group with respect to peak velocity, peak power output, and jump height in comparison to the OL and S group has also been reported in comparison to other power athletes (13).

The results of the JS testing provided some additional information concerning the higher force spectrum of the force–velocity curve. The PL, OL, and S groups consistently outperformed the C group only in peak force. The peak force produced by the OL group was again higher than either the PL or S groups at various loads. However, peak velocity did not define the groups, as it did in the CMJ. One of the most striking findings was that peak power was significantly higher in the OL group in comparison to the PL, S, and C groups in the 30% load condition. The S group dropped dramatically in peak power output in the JS trials in comparison to the previous CMJ trials. However, the S group still managed to have significantly higher jump heights in comparison to the PL and OL groups in various load conditions in the JS trials.

Over the spectrum of both the CMJ and JS trials, the comparison between the S and OL groups perhaps provided the most interesting findings. While the S and OL groups were similar in vertical jump height, the variables relating to the force plate measurements were different. The S group produced higher peak velocities and jump heights in comparison to the PL group, while the OL group produced higher peak velocities, higher peak forces, higher peak power outputs, and higher jump heights in comparison to the PL group. These measurements support our initial hypothesis. The OL group is both forceful and powerful. While the S group was not as forceful and powerful, this group still achieved high movement velocities. This information could be related back to training protocols in which the OL group performs high force, high velocity training (Olympic lifts) and the S group performs low force, high velocity training (sprinting, plyometrics). The PL group also supports this trend with equitable force outputs but deficient peak velocities, which again can be related back to high force, low velocity training performed by the PL group.

The data indicate that simply initiating a heavy load, slow velocity exercise (squat) in an explosive manner, as suggested by Behm and Sale (3), is an insufficient stimulus for improvements in muscle power, movement velocity, or jump height as shown by the performance of the PL group. Furthermore, in reference to the PL and C groups, it appears that performing high force, slow velocity training does little to improve peak velocity and jump height capabilities above that of nonweight-trained subjects without task practice (the PL group did not perform any type of vertical jump training). However, previous investigations on heavy squat training and improvement in vertical jump height do not support this, although multiple vertical jump testing sessions throughout the training period could be considered as task practice (11, 28). The necessity of task practice to transfer increases in leg muscle strength from heavy squatting into improvements in jump height is supported by a simulation study by Bobbert and Van Soest (4).

The data also indicate that the use of heavy resistance training and on-field low force, high velocity training (the majority of the S group utilized a combination of sprinting and plyometric training) results in the ability to generate high velocities and jump heights and achieve relatively high strength levels but does not allow for the use of the strength and high velocity movements simultaneously in comparison to the OL group. This is indicated by the performance of the S group. The OL group was able to utilize maximal strength at high velocities and thus produce the highest power outputs. This point is highlighted by the significantly higher power output produced by the OL group in comparison to the other three groups at the 30% jump squat load. These concepts are supported by a previous investigation comparing training with traditional weight training (high force, low velocity), maximal power exercises (moderate force, high velocity), and plyometrics (low force, high velocity) (29). That study showed that training with maximal power exercises improves both power output and vertical jump height in comparison to improvements only in jump height with plyometrics (29). Another investigation indicates significantly greater improvements in muscle power when using heavy squat and plyometric training simultaneously in comparison to performing heavy squats or plyometrics alone (1). Thus, it appears that the use of heavy squat training combined with low force, high velocity training (sprinting, plyometrics) may be sufficient for improvements in power and physical performance in the vertical plane, as shown by the S group. However, this training does not appear to be as effective for coincidental increases in maximal power and vertical jump height as training utilizing the Olympic lifts.

Practical Application

This investigation provides evidence that weight room training for athletes should be adapted to meet the demands of their on-field activities according to high force, low velocity (strength); high force, high velocity (strength, power); or low force, high velocity (performance, power) components. This investigation extends the specificity principle to include various divisions in power such as that shown by the OL (strength, power) and S (performance, power) groups. The S group could jump high but was not forceful in this action. The OL group could jump high and simultaneously produce high force and thus the highest power outputs. This indicates, e.g., that a volleyball player may only need heavy squat and plyometric training to induce increases in jump height. However, to maximize the ability to use high forces and high velocities simultaneously (as indicated by the OL group), which is needed, e.g., in a football block or tackle, training incorporating high force, high velocity movements (Olympic lifts or heavy load jump squats) may be required (6). This study provides preliminary evidence for future avenues of research into a comparison of Olympic lifts, heavy and light load jump squats, and heavy squat, plyometric programs and their differential effects on muscle strength, muscle power, and physical performance.

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