How Does Lower-Body and Upper-Body Strength Relate to Maximum Split Jerk Performance?

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Abstract

Soriano, MA, Jiménez-Ormeño, E, Amaro-Gahete, FJ, Haff, GG, and Comfort, P. How does lower-body and upper-body strength relate to maximum split jerk performance? *J Strength Cond Res* 36(8): 2102–2107, 2022—The aims of this study were to (I) determine the relationships between the maximum dynamic strength of the upper and lower body, measured by overhead press and back squat 1 repetition maximum (1RM) performances, and the split jerk (SJ) performance in trained weightlifters and (II) explore the magnitude of these relationships for men and women to establish sex-specific prediction equations. Twenty men (age: 28.9 ± 6.6 years; height: 1.8 ± 0.1 m; body mass [BM]: 82.5 ± 10.2 kg; weightlifting training experience: 4.2 ± 2.4 years) and 13 women (age: 27.7 ± 4.4 years; height: 1.7 ± 0.1 m; BM: 61.8 ± 5.2 kg; weightlifting training experience: 2.7 ± 1.7 years) competitive weightlifters participated. The 1RM performances of the overhead press, back squat, and SJ were assessed for all subjects. A very strong correlation exists between the back squat and overhead press, with maximum SJ performance for all subjects ($r = 0.97$; $p < 0.001$). Similarly, very strong correlations were found for men ($r = 0.90$, $p < 0.001$) and women ($r = 0.90$, $p = 0.0002$), separately. The coefficient of determination indicates that the prediction equation for the maximum SJ performance is quite accurate ($R^2 = 0.94$) for all subjects and men ($R^2 = 0.83$) and women ($R^2 = 0.81$), separately. These results provide evidence that the maximum strength of the upper and lower body are major contributors to SJ performance. In addition, SJ performance can accurately be predicted from the back squat and overhead press performances.

Key Words: weightlifting, overhead press, back squat, prediction equation, principal component analysis

Introduction

Muscular strength is strongly associated with athletic performance, with stronger athletes generally having enhanced force-time characteristics (e.g., rate of force development and power), a greater performance over a range of sport-specific tasks (e.g., jumping, sprinting, and lifting), and lower risk of injury (21,22). Because of the overall impact of strength on sporting performance, it is paramount that researchers and practitioners accurately quantify muscular strength levels, especially when maximal strength is used as an indicator of performance (12,21).

The 1 repetition maximum (1RM) test is a popular field test that is used to determine an athlete's maximum dynamic strength and to monitor changes in performance over time (1,12). The 1RM test is especially advantageous because it is relatively simple, requires relatively inexpensive equipment, and can be performed using the same exercises as those undertaken during regular training (12). Furthermore, in a recent meta-analysis, researchers demonstrated that the 1RM test has good to excellent reliability regardless of resistance training experience, exercise selection, part of the body assessed (upper or lower body), and sex or age of subjects evaluated (8). On the other hand, performing multiple 1RM tests could be fatiguing and time consuming, and therefore, if there are strong associations between exercises, it may be possible to predict the 1RM performance for numerous exercises based on the 1RM from 1 exercise (19).

In the sport of weightlifting, the maximum load lifted during the snatch and the clean and jerk (C&J) is summed to determine the competition total and the overall winner of the competition (17). To lift greater loads than their opponents, weightlifters are required to perform an impulsive triple extension of the hips, knees, and ankles (plantar flexion), generating peak forces, rates of force development, and power (6,17). It is well documented that these exercises are complex multijoint tasks that involve the whole-body performing a series of movements in a ballistic sequence of high-intensity muscular actions. However, although these exercises involve the whole body, the performance capabilities of competitive weightlifters seem to be primarily dependent on lower-body strength (6,17). In fact, the 1RM of each competitive lift (i.e., snatch and C&J) along with other lower-body strength measures, such as the back and front squats, is frequently used for programming percentages of 1RM during training and to monitor performance over time (18).

There is evidence that the maximum dynamic strength of the lower body is a major contributor for successful weightlifting performance (3,11,19). For example, Stone et al. (19) reported that the 1RM back squat was almost perfectly correlated with snatch and clean performance in well-trained male weightlifters ($r = 0.94$, $r = 0.95$, respectively; $p \leq 0.05$). Similarly, Carlock et al. (3) also

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reported strong correlations between the 1RM back squat and snatch and C&J performance in elite and academy weightlifters ($r = 0.94$, $r = 0.95$; $p \leq 0.05$). Interestingly, Lucero et al. (11) reported that the snatch and C&J performances are almost perfectly and linearly related to the front ($r = 0.92$, $r = 0.94$; $p < 0.01$) and back squat ($r = 0.91$, $r = 0.91$; $p < 0.01$) 1RM, although these lower-body strength measures were not measured directly but were based on a survey of 72 competitive male weightlifters providing self-reported 1RM performances. Although there seems to be a growing body of evidence that suggests that lower-body strength is a major contributor to weightlifting performance, there is minimal research examining the impact of upper-body strength on weightlifting performance.

To the best of our knowledge, the relationship between the maximum dynamic strength of the upper body and weightlifting performance has only been reported in 1 study (16). Specifically, the overhead press 1RM is strongly related to the split jerk (SJ) 1RM performance ($r = 0.90$, $p < 0.001$). Unfortunately, the researchers did not report the maximum dynamic strength of the lower body, which could have offered a more complete image of the strength needs related to weightlifting performance. Furthermore, it is important to consider whether the maximum dynamic strength of the upper and lower body may predict SJ performance.

Therefore, the aim of this study was to determine the relationships between the maximum dynamic strength of the upper and lower body, measured by the overhead press and back squat 1RM performances, and the SJ performance in trained weightlifters. A further aim of this study was to explore the magnitude of these relationships for men and women to establish sex-specific prediction equations. It was hypothesized that there would be strong correlations and linear relationships between the back squat and overhead press maximum strength and SJ performance. It was also hypothesized that SJ performance could be predicted from the back squat and overhead press 1RM performances in men and women.

Methods

Experimental Approach to the Problem

A cross-sectional study was designed to determine the relationships between 1RM performances of the maximum dynamic strength of the lower and upper body (measured by the back squat and overhead press 1RM test, respectively) and weightlifting performance (measured by the SJ) in competitive male and female weightlifters. Researchers have previously reported that the test-retest reliability of the overhead press (16), back squat (2,4), and SJ (15) 1RM performance is high (intraclass correlation coefficient [ICC]: 0.98, 0.99, and 0.99, respectively) and variation is low (coefficient of variation [CV]: 4.0, 2.1, and 0.8%, respectively), especially in trained subjects. Therefore, the 1RM test was performed once by all subjects. All tests were conducted in a randomized order and performed on separate days with ≥72 h of rest between assessments, over a maximum duration of 2 weeks. Verbal encouragement was provided throughout all maximal testing conditions. Subjects were asked to replicate their fluid and food intake 24 hours before the day of testing, to avoid strenuous exercise for 48 hours before testing, and to maintain any existing supplementation regimen throughout the duration of the study.

Subjects

Twenty male and 13 female competitive weightlifters volunteered to participate in this study (Table 1). Subjects were amateur competitors in regional and national tournaments in weightlifting. Furthermore, they were required to have ≥6 months of weightlifting experience and regularly (≥3 × week) performed weightlifting trainings. All subjects provided written informed consent before participation, with ethical approval provided by the institutional review board of Camilo José Cela University. The study conformed to the principles of World Medical Association's Declaration of Helsinki.

Procedures

For the overhead press and SJ, subjects completed a warm-up protocol designed to prepare them for a single 1RM assessment with methods previously described by Soriano et al. (15). Briefly, the warm-up consisted of dynamic activation and exercise-specific drills. Subsequently, 1 set of 5 repetitions was performed with a load that corresponded to 50% of self-estimated 1RM for the required exercise (overhead press or SJ). After 3 minutes of rest, another set of 5 repetitions was performed with a load that corresponded to 60% of self-estimated 1RM. Thereafter, 2 sets of 3 repetitions were performed with loads that corresponded to 70 and 85% of self-estimated 1RM, respectively. Subjects had 3–5 minutes of rest between these sets. After the warm-up, subjects rested for 5 minutes before the start of the 1RM test. For the back squat, subjects completed a modified protocol based on the study by Banyard et al. (2). Briefly, subjects started a general warm-up with 5 minutes of slight stationary cycling and dynamic stretching. Subsequently, subjects performed 1 set of 3 submaximal repetitions at 20, 40, and 60% of the previous back squat 1RM and, eventually, 1 repetition at 80 and 90%. Rest periods comprised

Table 1
Descriptive characteristics of the groups.*,†

Group	Sample size (n)	Age (y)	Height (cm)	BM (kg)	WL training experience (y)	Lower-body relative strength (BS·BM^{-1}) (kg·kg^{-1})	Upper-body relative strength (OP·BM^{-1}) (kg·kg^{-1})	Relative weightlifting performance (SJ·BM^{-1}) (kg·kg^{-1})
Males	20	28.9 ± 6.6	177.9 ± 5.6	82.5 ± 10.2	4.2 ± 2.4	1.9 ± 0.2	0.9 ± 0.1	1.4 ± 0.1
(95% CI)		(25.8–32.0)	(175.2–180.5)	(77.8–87.3)	(3.1–5.3)	(1.8–2.0)	(0.8–0.9)	(1.3–1.5)
[Range]		[18–42]	[169–190]	[59–102]	[1–12]	[1.5–2.3]	[0.7–1.0]	[1.1–1.8]
Females	13	27.7 ± 4.4	165.0 ± 4.9	61.8 ± 5.2	2.7 ± 1.7	1.5 ± 0.3	0.6 ± 0.1	1.1 ± 0.1
(95% CI)		(25.0–30.4)	(162.0–168.0)	(58.7–64.9)	(1.6–3.7)	(1.3–1.7)	(0.6–0.7)	(0.9–1.2)
[Range]		[20–34]	[158–173]	[59–102]	[0.5–6]	[0.9–2.1]	[0.5–0.9]	[0.6–1.2]

*BM = body mass, WL = weightlifting, 1RM = 1 repetition maximum, BS = back squat, OP = overhead press, SJ = split jerk.
†Measures are represented as mean and *SD*.

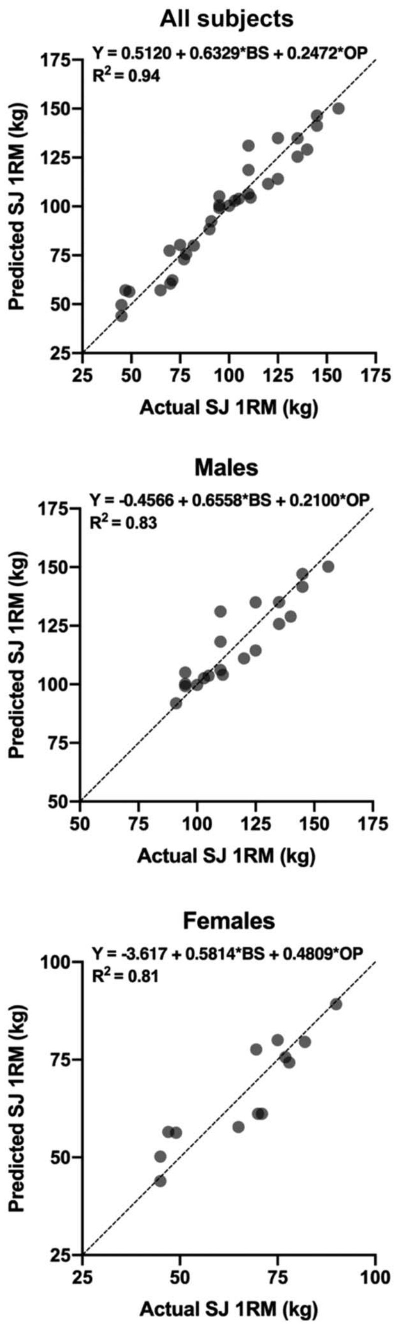

Figure 1. Comparison of the actual and predicted values of the 1RM during the split jerk for all subjects (upper panel), men (middle panel), and women (lower panel). BS = back squat; OP = overhead press; SJ = split jerk; 1RM = 1 repetition maximum.

3 minutes between warm-up sets. After the warm-up, subjects rested for 5 minutes before the start of the 1RM test.

The 1RM assessment for the overhead press and SJ started from a near-maximal load (95% of self-estimated 1RM), and each successful attempt was followed by an increment of the load of 2.5–5.0% until the 1RM was reached, allowing a maximum of five 1RM attempts, in accordance with the NSCA guidelines (9). Subjects rested for 3 to 5 minutes between attempts. In the overhead press, the lifter begins by standing with the barbell resting in the front rack position using a prone grip of medium width with the elbows oriented approximately at 45° to the floor. Then, the barbell was pressed upward throughout the full flexion of the shoulders and extension of the elbows to an overhead position while the trunk and the lower limbs provide stability. For the SJ, subjects performed a shallow countermovement, followed by fully extending the hips, knees, and ankles, accelerating the barbell upward then subsequently dropping under the barbell to catch the bar in a split stance, with shoulders flexed and elbows fully extended overhead. The barbell was taken out of jerk stands before starting each attempt to minimize the fatigue associated with the performance of the clean, which precedes the SJ in competitions (15). Subjects were placed between 2 high blocks and were allowed to drop the barbell over them. In the back squat, a maximum of five 1RM attempts were permitted, which did not include the submaximal warm-up repetitions previously performed up to 90% 1RM. Rest periods comprised 4–5 minutes between 1RM attempts. For each squat repetition, subjects were instructed to perform the eccentric phase in a controlled manner until full knee flexion was achieved (full depth). Once the eccentric phase was completed, subjects were told to immediately perform the concentric phase as fast and explosively as possible until the knees and hips were fully extended, aligned with the trunk in a standing still position. Importantly, the barbell was placed in a high bar position because it is the style frequently used by weightlifters (7,20) and had to remain in constant contact with the shoulders, whereas the feet were required to maintain contact with the floor. All testing sessions were performed using standardized Olympic barbells and plates (PowerKan Sports Equipment, Valladolid, Spain), lifting platforms, and power racks. A 20-kg Olympic barbell was used for men, whereas a 15-kg Olympic barbell was used for women.

Statistical Analyses

Normality of data was determined using the Shapiro-Wilk's test. Pearson's correlation coefficients (r) with 95% confidence intervals (CIs) and coefficient of determination (R^2) were calculated between the overhead press, back squat, and SJ performance to determine relationships between the upper-body and lower-body strength and weightlifting performance for all subjects and men and women, separately. An a priori alpha level was set at $p \leq 0.05$. Multiple correlation and regression analyses were conducted to explore relationships between the 1RM performances of the back squat, overhead press, and SJ and whether the SJ maximum performance could be predicted from the maximum dynamic strength of the lower and upper body for men and women, separately. Collinearity analysis was conducted to avoid the use of 2 correlated independent variables. The correlation coefficients were interpreted based on the recommendations of Schober et al. (13) where ≤0.10 represents negligible correlation, 0.10–0.39 weak correlation, 0.40–0.69 moderate correlation, 0.70–0.89 strong correlation, and ≥0.9 very strong correlation.

Principal component analysis (PCA) was implemented to identify the eigenvalues more related to the weightlifting performance. A test for the Kaiser-Mayer-Olkin criterion was performed for measuring sampling adequacy. The Barlett test for sphericity was used to determine the eligibility of the data for the PCA. A set of 6 variables were included and analyzed (i.e., SJ performance, back squat performance, overhead press performance, height, BM, and weightlifting training experience). These

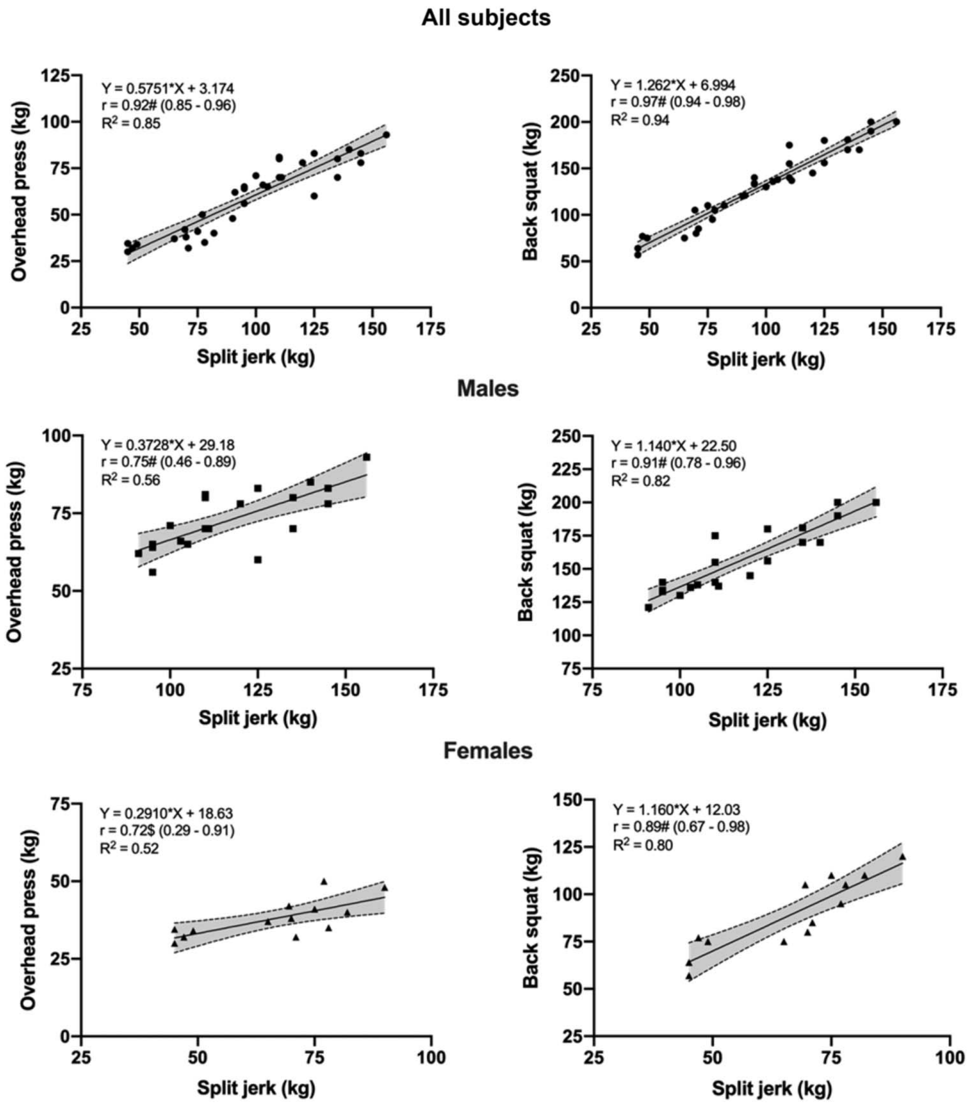

Figure 2. Relationships of the 1 repetition maximum (1RM) performance between the overhead press, back squat, and split jerk in all subjects (upper panel), men (middle panel), and women (lower panel). #$p < 0.001$, \$$p = 0.005$. The regression model, Pearson's correlation coefficient (r) with 95% confidence interval (gray area), and coefficient of determination (R^2) are depicted.

variables have previously been related to weightlifting performance and, specifically, SJ performance elsewhere (14,16,19). A parallel analysis technique and oblimin rotation were used for the PCA.

Results

A description of the mean, 95% CI, and range of subjects' age, height, BM, lower-body relative strength, upper-body relative strength, and relative weightlifting performance is presented in Table 1.

Based on the results of multiple correlation and regression analysis, almost a perfect correlation exists between the back squat and overhead press, as the independent variables, and the SJ as the dependent variable for all subjects ($r = 0.97$; $p < 0.001$). The estimate of the intercept was ß = 0.51, with a standard error (S_E) of 4.62 and associated 95% CI (−8.93 to 9.95). Collinearity was interpreted based on the results of the Durbin-Watson test for autocorrelation (2.13, $p = 0.73$), and the variance inflation factor test was applied to the back squat and overhead press (7.46). The coefficient of determination was very high ($R^2 = 0.94$) for all subjects (Figure 1). Specifically, very strong and significant correlations were found between the overhead press and SJ 1RM performance and between the back squat and SJ 1RM performances for all subjects ($r = 0.92$, $r = 0.97$, respectively; $p < 0.001$) (Figure 2). Similarly, there was a significant and almost perfect correlation between the back squat and overhead press, as the independent variables, and the SJ as the dependent variable for men ($r = 0.90$, $p < 0.001$) and women ($r = 0.90$, $p = 0.0002$). The coefficient of determination was high for men ($R^2 = 0.83$) and women ($R^2 = 0.81$) (Figure 1). Specifically, there were strong and significant correlations between the overhead press and SJ 1RM performance for both men ($r = 0.75$, $p \leq 0.005$) and women ($r = 0.72$, $p \leq 0.005$), whereas both sexes demonstrated very strong and significant correlations between the back squat and SJ 1RM performances (men: $r = 0.91$, women: $r = 0.89$; $p < 0.001$) (Figure 2).

The prediction equations for men (Eq 1) and women (Eq 2) were as follows:

$$\text{SJ 1RM performance} = -0.4566 + 0.6558*BS + 0.2100*OP \quad (1)$$

$$\text{SJ 1RM performance} = -3.617 + 0.5814*BS + 0.4809*OP \quad (2)$$

Where *BS* and *OP* are the back squat and the overhead press 1RM performances in kg. In addition, scatter plots of the comparison between the actual and predicted SJ 1RM performances were developed for all subjects, men, and women (Figure 1).

Based on the Kaiser-Mayer-Olkin and Barlett tests, the criterion for sampling adequacy (KMO = 0.78) and sphericity assumption ($p < 0.001$) was satisfied for PCA. Considering the results of the PCA, only 1 principal component (PC) with 4.57 of eigenvalue and accounting for 77.2% of the variance was identified. Five of the 6 variables had a high loading on the PC: SJ performance (0.96), back squat performance (0.97), overhead press performance (0.94), height (0.91), and BM (0.92), except for weightlifting training experience (0.40). Similarly, the uniqueness values were lower for the SJ performance (0.08), squat (0.07), and press (0.11) than those of the height (0.18), BM (0.16), and weightlifting training experience (0.84).

Discussion

The main finding of this study was that there were strong relationships between the back squat, overhead press, and SJ 1RM performance in trained weightlifters. A novel finding of this study was the ability to predict the SJ 1RM performance from the back squat and overhead press. These findings are important for strength and conditioning coaches because they illustrate the extent that the maximum strength of the upper and lower body are related to the SJ 1RM performance.

The SJ is a unique movement where the largest loads are lifted to an overhead position (14). Researchers have widely suggested that the performance capabilities of weightlifting seem to primarily depend on lower-body strength (6,17,19). However, Soriano et al. (16) reported a strong relationship between the overhead press and SJ performance ($r = 0.90$, $p < 0.001$), suggesting that the strength of the upper body is also related to weightlifting performance. The results of this study support previous results with very strong correlations between the overhead press, back squat, and SJ 1RM performance ($r = 0.97$, $p < 0.001$) found in competitive weightlifters. Collectively, these results provide evidence that SJ performance is a function of both upper-body and lower-body strength.

Multiple correlation and regression analyses were conducted to determine whether the SJ performance could be predicted from the maximum dynamic strength of the lower and upper body (SJ ~ intercept + back squat + overhead press). A novel finding of this study was that an almost perfect correlation was found between back squat and overhead press as the independent variables and the SJ as the dependent variable for all subjects ($r = 0.97$). In addition, the R^2 was very high (0.94) and the S_E low (4.62), suggesting that back squat and overhead press performances can explain 94% of the variance in SJ performance, in competitive weightlifters, accurately (Figure 1). These findings are slightly different compared with previous results, where Soriano et al. (16) reported a lower coefficient of determination between the overhead press and SJ performance for men ($R^2 = 0.81$). Likely, differences between these findings are attributed to the addition of the lower-body dynamic strength to the prediction equation. Interestingly, Lucero et al. (11) reported lower coefficients of determination for the back squat ($R^2 = 84$) and front squat ($R^2 = 88$) compared to the C&J performance. Again, the differences in these findings may be explained by the fact that both lower-body and upper-body dynamic strength were added to the prediction equation for the SJ maximum performance. In addition, Lucero et al. (11) investigated the prediction of the C&J performance and not the SJ performance alone.

Principal component analysis is a statistical technique used to reduce the dimensionality of a data set while preserving its variability and statistical information (10). One key point is to find new variables that are linear functions of those in the data set, known as principal components, that successively maximize variance to solve an eigenvalue (10). In this study, only one principal component (PC1) with 4.57 of eigenvalue and accounting for 77.2% of the variance was identified. This component was composed by 6 variables, which have previously been related to weightlifting performance (14,16,19). As expected, performance-related variables had a higher loading on the PC1 (SJ performance = 0.96, back squat performance = 0.97, and overhead press performance = 0.94), followed by anthropometric-related variables (height = 0.91 and BM = 0.92), and finally, weightlifting training experience (0.40). To the best of our knowledge, this is the first study that includes a PCA for the multifactorial detection of weightlifting performance. The use of PCA may be beneficial for researchers and practitioners because the number of relevant variables related to weightlifting performance and identified in previous studies (performance-related, anthropometric-related, and weightlifting training experience) (5,16,19,20) can be reduced to a single weightlifting performance component.

In conclusion, the findings of this study provide more evidence that the maximum strength of the upper and lower body are major contributors to weightlifting performance, specifically, SJ performance. A limitation in this study is that the strong correlations between 1RM performances might be due to the heterogeneity by means of height, BM, and relative strength in the weightlifters' sample analyzed. Thus, further research is needed in this area to clarify and simplify how the relevant variables are related to weightlifting performance and to determine whether an increase in back squat or overhead press performance results in an increase in SJ performance in a more homogeneous weightlifters' sample (i.e., within a given weight category, similar relative strength, etc).

Practical Applications

A most relevant application of this study is that to optimize SJ performance in competitive weightlifters; it is important to include exercises to develop both lower-body and upper-body strength because upper-body and lower-body maximum strength is related to the SJ performance. Another relevant application of this study is that the SJ performance can be predicted from the back squat and overhead press performances, accurately. In fact, the SJ performance can be explained by as much as 94% based on the multiple regression analysis for all subjects (Figure 1). Furthermore, sex-specific equations are provided for males (SJ 1RM performance = −0.4566 + 0.6558 * BS + 0.2100 * OP) and females (SJ 1RM performance = −3.617 + 0.5814 * BS + 0.4809 * OP) competitive weightlifters. This is of practical importance to monitor variations and set training goals by practitioners within a strength and conditioning program for competitive weightlifters.

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