ORIGINAL INVESTIGATION

1RM MEASURES OR MAXIMUM BAR-POWER OUTPUT: WHICH IS MORE RELATED TO SPORT PERFORMANCE?

Running head: 1RM and bar-power output in elite athletes

Abstract

Purpose: This study compared the associations between optimum power loads and 1-repetition maximum (1RM) values (assessed in half-squat [HS] and jump squat [JS] exercises) and multiple performance measures in elite athletes. **Methods:** Sixty-one elite athletes (fifteen Olympians) from four different sports (track and field [sprinters and jumpers], rugby sevens, bobsled, and soccer) performed squat and countermovement jumps, HS exercise (for assessing 1RM), HS and JS exercises (for assessing bar-power output), and sprint tests (60-m for sprinters and jumpers and 40-m for the other athletes). Pearson's product moment correlation test was used to determine relationships between 1RM and bar-power outputs with vertical jumps and sprint times in both exercises. **Results:** Overall, both measurements were moderately to near perfectly related to speed performance (*r* values varying from -0.35 to -0.69 for correlations between 1RM and sprint times, and from -0.36 to -0.91 for correlations between bar-power outputs and sprint times; $P < 0.05$). However, on average, the magnitude of these correlations was stronger for power-related variables, and only the bar-power outputs were significantly related to vertical jump height. **Conclusions:** The bar-power outputs were more strongly associated with sprint-speed and power performance than the 1RM measures. Therefore, coaches and researchers can use the bar-power approach for athlete testing and monitoring. Due to the strong correlations presented, it is possible to infer that meaningful variations in bar-power production may also represent substantial changes in actual sport performance.

Keywords: maximum strength, optimal load, elite athletes, muscle power, bar-velocity.

Introduction

Maximum dynamic strength assessments, also called one-repetition maximum (1RM) tests, are widely used by coaches and researchers to both evaluate neuromuscular performance and determine training loads.[1] The prescription of strength-power training is usually based on different percentages of 1RM, according to the objectives and needs of a given athlete or sport discipline.[1, 2] For example, programs designed to develop maximum strength capacity tend to adopt loading ranges varying between 80 and 100% 1RM; whereas programs focused on developing muscle power normally prioritize the use of exercises performed with light to moderate loads (e.g., 30 to 45% 1RM).[3-5] Thus, independent of their resistance training goals, athletes are often required to perform 1RM tests.

Due to the inherent difficulties in applying 1RM tests[6-8] (and thus monitoring the resistance-training load), velocity-based training (VBT)[9, 10] has emerged as a practical and advantageous alternative to control resistance training intensity.[11, 12] Indeed, the strong relationship between force and velocity enable practitioners to rapidly estimate relative load (i.e., % 1RM), by simply monitoring movement velocity.[11] Several investigations have provided useful information on VBT, reporting reference data which can be precisely used to monitor loading intensity in different exercises.[10, 11] Nevertheless, this approach normally correlates movement velocities with standard 1RM measures,[13, 14] compromising its applicability as a novel training strategy. Furthermore, recent studies have brought into question the theoretical concepts behind "maximum dynamic strength" assessments, which (in essence) represent only the higher mass that an athlete can move during a maximum-effort resistance exercise.[15, 16] For these authors, the fact that this scalar measure (i.e., mass) does not simultaneously reflect the force and velocity applied by the athlete against an external resistance could hamper its use in high-performance sport, where time and velocity play a critical role in determining the effectiveness of force application.[15]

With this in mind, more recently, the use of the "optimum power load" (i.e., load able to maximize power production) has been proposed in athletes' training programs.[16, 17] Briefly, instead of using reference loads based solely on scalar measures, coaches can adopt a training strategy which considers at the same time the force and velocity applied to the barbell, thus optimizing the power production in this external implement. This load is usually determined in a progressive load test, performed until a decrease in subject's power output is observed.[16, 17] Nonetheless, it appears that these optimized loads always occur at a narrow range of bar-velocities,[17, 18] which strongly facilitates resistance training monitoring and prescription. Based on these ranges, for example, coaches can increase or decrease the load magnitude as soon as the subject leaves the target (velocity) zone.[17, 18] Importantly, it has been shown that training within optimum power zones may be an effective way to improve strength and power abilities at both ends of the force-velocity curve (i.e., low-force, high-velocity portion; and high-force, low-velocity portion).[5, 8] From these findings, it may be inferred that numerous sport disciplines could benefit from using this alternative resistance training scheme rather than more traditional 1RM-based methods.

To examine the relationships between this specific range of loads and multiple performance measures in elite athletes from different sports is an important first step in exploring the usefulness and effectiveness of this novel approach. Accordingly, comparing the magnitude of these respective correlations with the magnitude of more established relationships (e.g., correlations between 1RM and performance measures)[19, 20] could enable practitioners and researchers to better select appropriate training strategies for their athletes. Thus, the aims of the present study were to: (1) analyze the correlations between bar-power outputs (under optimum loading conditions) and 1RM values (assessed in half-squat [HS] and jump squat [JS] exercises), and multiple performance measures in elite athletes from a range of sport disciplines; and (2) assess the sensitivity and specificity of the bar-power approach for athlete testing and monitoring.

Methods

Subjects

Sixty-one elite athletes from four different sports (14 track & field sprinters and jumpers: 23.9 ± 5.7 years, 66.1 ± 8.7 kg, 176.6 ± 7.8 cm; 18 rugby sevens players: 25.2 ± 3.1 years, 87.9 ± 7.8 kg, 181.5 ± 7.2 cm; 8 bobsled athletes: 28.7 ± 6.5 years, 89.0 ± 9.6 kg, 181.9 ± 9.7 cm; and 21 professional soccer players: 24.8 ± 4.5 years, 66.9 ± 7.6 kg, 176.0 ± 8.5 cm) participated in this study. All participants had at least five years of resistance training experience and, due to their professional training routine, performed a minimum of three and a maximum of five strength-power training sessions per week. The sample comprised 15 athletes who participated in the previous Summer and Winter Olympic Games (10 in Rio de Janeiro 2016 and 5 in PyeongChang 2018). The other athletes were part of the Brazilian National Teams, competing at national and international levels. The professional soccer players participated in the first division of the *"Paulista Championship"*, the most important Brazilian State Championship. Before participating in the study, athletes signed an informed consent form. The study was approved by the Anhanguera-Bandeirante University Ethics Committee (registration number 926.260).

Study Design

The athletes involved in this study were assessed during the competitive phase of the season and were well familiarized with testing procedures. Physical tests were performed on two consecutive days in the following order: Day 1) squat jumps (SJ) and countermovement jumps (CMJ) and 1RM in the HS exercise; Day 2) assessment of the maximum power outputs in the HS and JS exercises and a sprint test. After the first day, athletes rested until the next day of assessments. During this period, they were instructed to maintain their nutritional and sleep habits and to arrive at the sports laboratory in a fasted state for at least 2-h, avoiding alcohol and caffeine consumption for at least 48-h before the tests. A standardized warm-up was performed before the tests comprising light to moderate self-selected runs for 5-min, and prior to maximal tests sub-maximal attempts at each test were also performed. Between each test, a 15-min rest interval was implemented to explain the next procedures and adjust the testing devices.

Testing procedures

The SJ and CMJ were performed on a validated contact-mat (Elite Jump, S2 sports, Brazil)[21] with the hands on the hips. Five attempts for each jump were allowed and the highest jump of each mode was retained. A 1RM test in the HS exercise was performed on a Smith-machine device (Hammer Strength Equipment, Rosemont, USA) following the standard procedures described elsewhere (Figure 1).[6] Barbell-mean, mean propulsive, and peak power outputs (MP, MPP, and PP, respectively) were assessed in the HS and JS exercises on the Smith-machine using a linear encoder (T-Force, Dynamic Measurement System; Ergotech Consulting, Murcia, Spain), as previously described (Figure 2).[17] Briefly, to determine the optimal power load, the test started at a load corresponding to 40% of the athlete's body mass. Then, a load of 10% of body mass was gradually added in each set, until a clear decrement in the bar power was observed.[17] The loads corresponding to the highest power outputs in both exercises were retained for analysis.[17, 18] Both 1RM and power outputs were normalized to the athletes' body-mass (BM). For the sprint test, sprinters and jumpers performed a 60-m sprint test, whereas the other athletes sprinted over a total distance of 40-m. Five pairs of photocells (Smart-Speed, Fusion Equipment, Brisbane, AUS) were positioned at distances of zero, 10-, 20-, 30-, and 40-m along the sprinting course, and an additional pair was placed at 60-m to assess sprinters and jumpers. Athletes performed two sprints and the best attempt was retained. All tests used herein presented high levels of reliability and consistency (ICC > 0.92 and CV <4%, for all performance measures).[22]

*****INSERT FIGURE 1 HERE*****

*****INSERT FIGURE 2 HERE*****

Statistical analysis

Data normality was confirmed via the Kolmogorov-Smirnov test. The Pearson's product moment correlation test was used to determine the relationships between 1RM and power outputs in both exercises with vertical jumps and sprinting velocities. Correlation values were qualitatively assessed using the criteria established by Hopkins et al.[22], as follows: <0.1, trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large; >0.9 nearly perfect. The level of significance was set at $P < 0.05$.

Results

Descriptive data of the physical tests performed are presented in table 1. Table 2 shows the correlations between 1RM and power outputs in the HS and JS exercises with the vertical jumps and 60-m sprinting times. For all power outputs significant correlations were observed between the SJ and CMJ heights (varying between 0.58 and 0.82; $P < 0.05$), while no significant correlations were found between 1RM and the vertical jumps. The highest correlation values were observed between the different power outputs and 60-m sprint time (varying between -0.80 and -0.91; $P < 0.05$), while the correlation between the 1RM with the same sprint distance was -0.63 ($P < 0.05$).

*****INSERT TABLE 1 HERE*****

*****INSERT TABLE 2 HERE*****

Discussion

This study examined the relationships between 1RM values and maximum power outputs with multiple performance measures in elite athletes from different sports. Overall, both measurements were significantly related to speed-power variables (with the exception of SJ, CMJ and time 5-m, and 1RM). However, on average, the magnitude of these correlations was stronger for power-related variables, indicating that these outputs may be more strongly associated with sport-performance than 1RM loads.

The association between 1RM measures and performance has been extensively described in many studies and within a recent review.[20] Wisloff et al.[23] reported significant correlations between half-squat 1RM and sprint and jump performance (from 0.71 to 0.94) in professional soccer players. Similarly, McBride et al. (2009) found significant relationships among a series of speed-tests (5, 10, and 40-yard) and back-squat 1RM, emphasizing the importance of normalizing 1RM values by the athletes' BM (as relative values) to strengthen the associations between strength and performance measures.[19] In the present study, both 1RM and power outputs were expressed in relative values, which likely contributed to increase the magnitude of the correlations observed (Table 2). Nonetheless, as previously mentioned, these values were higher for power-related variables and, notably, only these outputs were significantly associated with vertical jump performance.

Requena et al.[24] reported similar results with well-trained sprinters, not finding significant relationships between relative measures of squat 1RM and CMJ height. In contrast, relative power production (in both squat and JS exercises) were found to be moderately related to jump ability and maximal speed over different distances (from 20- to 80-m). Accordingly, Loturco et al.[25] showed that both the MPP and the magnitude of the load lifted at the optimum zone are highly correlated to sprint and jump capacities (r ~ 0.80) in professional sprinters. These data are very similar to those described herein, confirming the usefulness of the bar-power approach in assessing athletic performance, especially in elite athletes. The opportunity to use ranges of loads which optimize the force and velocity applied to the barbell at the same time[15, 26] (instead of only considering the maximum mass moved during a maximum effort [i.e., 1RM]) may better reflect the abilities required in sport-tasks, where athletes are frequently required to move substantial amounts of loads at high speeds (e.g., the BM during a vertical jump or maximal sprints).[25, 27, 28] Although this mechanical parameter does not represent “total power of the system” (i.e., system-power)[15, 16], the bar-power output can be used not only to monitor strength and power capacities, but also to discriminate athletes with different performance levels and training backgrounds.[29]

We recognize that the 1RM measurement is widely used to prescribe and control training intensity, and there are several studies confirming its efficacy for such purposes.[1, 2, 13] Nevertheless, it is worth noting that, in terms of assessing athletes’ performance, the relationship with specific physical capabilities (e.g., jumping and sprinting) is a relevant criterion for test selection.[19, 23, 25] Furthermore, there are potential risks involved in 1RM testing,[6-8] which compromises its frequent use in competitive sports, where the constant evaluation of physical performance is of fundamental importance. More importantly, there is a significant limitation in considering a given scalar variable (i.e., mass) as a "strength measurement".[15, 26] In this context, it is critical to emphasize that the ability to efficiently accelerate relative loads (and thus reach higher movement velocities) is a selective factor in different sport disciplines.[12, 25, 30, 31] The finding that the bar-power output is more strongly associated with sport-performance than 1RM measures indicates that this novel and alternative method might be an effective way to assess elite athletes. Due to the high levels of precision and consistency presented by all power variables, based on their preferences and possibilities (i.e., device features), practitioners can use MP, MPP, or PP to estimate and define the optimum power zones, in both JS and HS exercises.

Practical Applications

Frequent monitoring of athletes' performance is essential in professional sports, serving as a basis for adjusting training loads and methods, and evaluating individual progress. Therefore, the use of applied, safe, and timesaving assessment tools becomes crucial for the development of better and more effective training programs. The bar-power approach is a practical training and testing strategy, which has been shown to be closely related to actual performance[25, 30, 31] and produce significant improvements in physical abilities at both ends of the force-velocity curve.[5, 8] In this study, we demonstrated that the bar-power outputs are more strongly associated with speed and power performances in elite athletes than 1RM measurements. With this in mind, coaches and researchers are encouraged to assess the power production directly on the barbell to evaluate the strength-power performance of their athletes. Despite the cross-sectional nature of our data, due to the large correlations presented here, it is possible to infer that meaningful variations in bar-power production may also represent substantial changes in athletic performance. Further studies should be conducted to test the relationships between bar-power output and alternative performance measures (e.g., repeated-sprint ability) and sport-tasks (e.g., change of direction tasks).

Conclusions

The bar-power approach is an effective testing strategy, which can be quickly and easily implemented to evaluate athletes from different sports. The bar-power output collected at the optimum power zone is closely related to athletic performance.

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FIGURE CAPTIONS

Figure 1. A National rugby sevens player performing a 1RM test in the half squat exercise.

Figure 2. An Olympic sprinter performing a loaded jump squat at the optimum power zone.

Table 1. Descriptive data of the vertical jumps, 1 repetition maximum (RM) in the half-squat exercise (HS), bar-power outputs in the HS and jump squat (JS) exercises, and sprinting times in elite athletes from different sports disciplines.

	Mean ± SD	**90% confidence limits**	
		Lower	**Upper**
SJ (cm)	41.89 ± 4.40	40.65	43.13
CMJ (cm)	43.89 ± 4.62	42.59	45.19
1RM (kg.kg^{-1})	2.54 ± 0.54	2.43	2.65
MP HS (W.kg^{-1})	7.90 ± 1.33	7.62	8.18
MPP HS (W.kg^{-1})	10.11 ± 1.59	9.78	10.45
PP HS (W.kg^{-1})	22.76 ± 5.14	21.68	23.84
MP JS (W.kg^{-1})	8.17 ± 1.77	7.80	8.55
MPP JS (W.kg^{-1})	11.76 ± 2.51	11.24	12.29
PP JS (W.kg^{-1})	25.85 ± 5.86	24.62	27.09
Time 5-m (s)	1.01 ± 0.05	1.00	1.02
Time 10-m (s)	1.70 ± 0.09	1.68	1.72
Time 20-m (s)	2.92 ± 0.12	2.90	2.95
Time 30-m (s)	4.03 ± 0.16	3.98	4.07
Time 40-m (s)	5.07 ± 0.20	5.02	5.12
Time 60-m (s)	7.18 ± 0.36	7.02	7.34

Note: SD: standard deviation; SJ: squat jump; CMJ: countermovement jump; MP: mean power; MPP; mean propulsive power; PP: peak power; *both 1RM load and power outputs were normalized by the athletes' body mass.

Table 2. Correlations (± 90% confidence intervals) between vertical jump performances and sprinting time with maximum dynamic strength in the half-squat (HS) exercise and bar-power outputs in the HS and jump squat (JS) exercises in elite athletes from different sports disciplines.

	1RM	MPP HS	MP HS	PP HS	MPP JS	MP JS	PP JS
SJ	0.26 (0.20)	0.63 (0.13)*	0.61 (0.14)*	0.58 (0.14)*	0.78 (0.09)*	0.69 (0.11)*	0.76 (0.09)*
CMJ	0.24 (0.20)	0.66 (0.12)*	0.66 (0.12)*	0.62 (0.13)*	0.82 (0.07)*	0.79 (0.08)*	0.82 (0.07)*
Time 5-m	0.16 (0.21)	-0.36 (0.19)*	-0.50 (0.16)*	-0.56 (0.15)*	-0.58 (0.14)*	-0.60 (0.14)*	-0.56 (0.15)*
Time 10-m	-0.35 (0.19)*	-0.52 (0.16)*	-0.44 (0.17)*	-0.51 (0.16)*	-0.46 (0.17)*	-0.37 (0.18)*	-0.40 (0.18)*
Time 20-m	-0.46 (0.17)*	-0.71 (0.11)*	-0.65 (0.12)*	-0.65 (0.12)*	-0.65 (0.12)*	-0.59 (0.14)*	-0.59 (0.14)*
Time 30-m	-0.51 (0.16)*	-0.81 (0.08)*	-0.72 (0.10)*	-0.77 (0.09)*	-0.82 (0.07)*	-0.77 (0.09)*	-0.77 (0.09)*
Time 40-m	-0.69 (0.11)*	-0.81 (0.08)*	0.71 (0.11)*	-0.69 (0.11)*	-0.78 (0.09)*	-0.70 (0.11)*	-0.70 (0.11)*
Time 60-m	-0.63 (0.13)*	-0.88 (0.05)*	-0.91 (0.04)*	-0.80 (0.08)*	-0.91 (0.04)*	-0.90 (0.04)*	-0.80 (0.08)*

Note: SJ: squat jump; CMJ: countermovement jump; 1RM: one repetition maximum; MP: mean power; MPP; mean propulsive power; PP: peak power; **both 1-RM load and power outputs were normalized by the athletes' body mass; *P< 0.05.