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1 **ORIGINAL INVESTIGATION**

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3 **1RM MEASURES OR MAXIMUM BAR-POWER OUTPUT: WHICH IS MORE**

4 **RELATED TO SPORT PERFORMANCE?**

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

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26 **Abstract**

27 **Purpose:** This study compared the associations between optimum power loads and 1-
28 repetition maximum (1RM) values (assessed in half-squat [HS] and jump squat [JS]
29 exercises) and multiple performance measures in elite athletes. **Methods:** Sixty-one elite
30 athletes (fifteen Olympians) from four different sports (track and field [sprinters and
31 jumpers], rugby sevens, bobsled, and soccer) performed squat and countermovement
32 jumps, HS exercise (for assessing 1RM), HS and JS exercises (for assessing bar-power
33 output), and sprint tests (60-m for sprinters and jumpers and 40-m for the other athletes).
34 Pearson's product moment correlation test was used to determine relationships between
35 1RM and bar-power outputs with vertical jumps and sprint times in both exercises.
36 **Results:** Overall, both measurements were moderately to near perfectly related to speed
37 performance (r values varying from -0.35 to -0.69 for correlations between 1RM and
38 sprint times, and from -0.36 to -0.91 for correlations between bar-power outputs and
39 sprint times; $P < 0.05$). However, on average, the magnitude of these correlations was
40 stronger for power-related variables, and only the bar-power outputs were significantly
41 related to vertical jump height. **Conclusions:** The bar-power outputs were more strongly
42 associated with sprint-speed and power performance than the 1RM measures. Therefore,
43 coaches and researchers can use the bar-power approach for athlete testing and
44 monitoring. Due to the strong correlations presented, it is possible to infer that meaningful
45 variations in bar-power production may also represent substantial changes in actual sport
46 performance.

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

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50

51 **Introduction**

52 Maximum dynamic strength assessments, also called one-repetition maximum
53 (1RM) tests, are widely used by coaches and researchers to both evaluate neuromuscular
54 performance and determine training loads.¹ The prescription of strength-power training
55 is usually based on different percentages of 1RM, according to the objectives and needs
56 of a given athlete or sport discipline.^{1, 2} For example, programs designed to develop
57 maximum strength capacity tend to adopt loading ranges varying between 80 and 100%
58 1RM; whereas programs focused on developing muscle power normally prioritize the use
59 of exercises performed with light to moderate loads (e.g., 30 to 45% 1RM).³⁻⁵ Thus,
60 independent of their resistance training goals, athletes are often required to perform 1RM
61 tests.

62 Due to the inherent difficulties in applying 1RM tests⁶⁻⁸ (and thus monitoring the
63 resistance-training load), velocity-based training (VBT)^{9, 10} has emerged as a practical
64 and advantageous alternative to control resistance training intensity.^{11, 12} Indeed, the
65 strong relationship between force and velocity enable practitioners to rapidly estimate
66 relative load (i.e., % 1RM), by simply monitoring movement velocity.¹¹ Several
67 investigations have provided useful information on VBT, reporting reference data which
68 can be precisely used to monitor loading intensity in different exercises.^{10, 11} Nevertheless,
69 this approach normally correlates movement velocities with standard 1RM measures,^{13,}
70 ¹⁴ compromising its applicability as a novel training strategy. Furthermore, recent studies
71 have brought into question the theoretical concepts behind “maximum dynamic strength”
72 assessments, which (in essence) represent only the higher mass that an athlete can move
73 during a maximum-effort resistance exercise.^{15, 16} For these authors, the fact that this
74 scalar measure (i.e., mass) does not simultaneously reflect the force and velocity applied
75 by the athlete against an external resistance could hamper its use in high-performance

76 sport, where time and velocity play a critical role in determining the effectiveness of force
77 application.¹⁵

78 With this in mind, more recently, the use of the “optimum power load” (i.e., load
79 able to maximize power production) has been proposed in athletes’ training programs.^{16,}

80 ¹⁷ Briefly, instead of using reference loads based solely on scalar measures, coaches can
81 adopt a training strategy which considers at the same time the force and velocity applied
82 to the barbell, thus optimizing the power production in this external implement. This load
83 is usually determined in a progressive load test, performed until a decrease in subject’s
84 power output is observed.^{16, 17} Nonetheless, it appears that these optimized loads always

85 occur at a narrow range of bar-velocities,^{17, 18} which strongly facilitates resistance training
86 monitoring and prescription. Based on these ranges, for example, coaches can increase or
87 decrease the load magnitude as soon as the subject leaves the target (velocity) zone.^{17, 18}

88 Importantly, it has been shown that training within optimum power zones may be an
89 effective way to improve strength and power abilities at both ends of the force-velocity
90 curve (i.e., low-force, high-velocity portion; and high-force, low-velocity portion).^{5, 8}

91 From these findings, it may be inferred that numerous sport disciplines **could benefit from**
92 **using this alternative resistance training scheme rather than more traditional 1RM-based**
93 **methods.**

94 To examine the relationships between this specific range of loads and multiple
95 performance measures in elite athletes from different sports is an important first step in
96 exploring the usefulness and effectiveness of this novel approach. Accordingly,
97 comparing the magnitude of these respective correlations with the magnitude of more
98 established relationships (e.g., correlations between 1RM and performance measures)^{19,}
99 ²⁰ could enable practitioners and researchers to better select appropriate training strategies
100 for their athletes. Thus, the aims of the present study were to: (1) **analyze the correlations**

101 between bar-power outputs (under optimum loading conditions) and 1RM values
102 (assessed in half-squat [HS] and jump squat [JS] exercises), and multiple performance
103 measures in elite athletes from a range of sport disciplines; and (2) assess the sensitivity
104 and specificity of the bar-power approach for athlete testing and monitoring.

105

106 **Methods**

107 *Subjects*

108 Sixty-one elite athletes from four different sports (14 track & field sprinters and
109 jumpers: 23.9 ± 5.7 years, 66.1 ± 8.7 kg, 176.6 ± 7.8 cm; 18 rugby sevens players: 25.2
110 ± 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
111 kg, 181.9 ± 9.7 cm; and 21 professional soccer players: 24.8 ± 4.5 years, 66.9 ± 7.6 kg,
112 176.0 ± 8.5 cm) participated in this study. All participants had at least five years of
113 resistance training experience and, due to their professional training routine, performed a
114 minimum of three and a maximum of five strength-power training sessions per week. The
115 sample comprised 15 athletes who participated in the previous Summer and Winter
116 Olympic Games (10 in Rio de Janeiro 2016 and 5 in PyeongChang 2018). The other
117 athletes were part of the Brazilian National Teams, competing at national and
118 international levels. The professional soccer players participated in the first division of
119 the "Paulista Championship", the most important Brazilian State Championship. Before
120 participating in the study, athletes signed an informed consent form. The study was
121 approved by the Anhanguera-Bandeirante University Ethics Committee (registration
122 number 926.260).

123

124 *Study Design*

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

137

138 *Testing procedures*

139 The SJ and CMJ were performed on a validated contact-mat (Elite Jump, S2
140 sports, Brazil)²¹ with the hands on the hips. Five attempts for each jump were allowed
141 and the highest jump of each mode was retained. A 1RM test in the HS exercise was
142 performed on a Smith-machine device (Hammer Strength Equipment, Rosemont, USA)
143 following the standard procedures described elsewhere (Figure 1).⁶ Barbell-mean, mean
144 propulsive, and peak power outputs (MP, MPP, and PP, respectively) were assessed in
145 the HS and JS exercises on the Smith-machine using a linear encoder (T-Force, Dynamic
146 Measurement System; Ergotech Consulting, Murcia, Spain), as previously described
147 (Figure 2).¹⁷ Briefly, to determine the optimal power load, the test started at a load
148 corresponding to 40% of the athlete's body mass. Then, a load of 10% of body mass was
149 gradually added in each set, until a clear decrement in the bar power was observed.¹⁷ The

150 loads corresponding to the highest power outputs in both exercises were retained for
151 analysis.^{17, 18} Both 1RM and power outputs were normalized to the athletes' body-mass
152 (BM). For the sprint test, sprinters and jumpers performed a 60-m sprint test, whereas the
153 other athletes sprinted over a total distance of 40-m. Five pairs of photocells (Smart-
154 Speed, Fusion Equipment, Brisbane, AUS) were positioned at distances of zero, 10-, 20-
155 , 30-, and 40-m along the sprinting course, and an additional pair was placed at 60-m to
156 assess sprinters and jumpers. Athletes performed two sprints and the best attempt was
157 retained. All tests used herein presented high levels of reliability and consistency (ICC >
158 0.92 and CV <4%, for all performance measures).²²

159

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

161

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

163

164 *Statistical analysis*

165 Data normality was confirmed via the Kolmogorov-Smirnov test. The Pearson's
166 product moment correlation test was used to determine the relationships between 1RM
167 and power outputs in both exercises with vertical jumps and sprinting velocities.
168 Correlation values were qualitatively assessed using the criteria established by Hopkins
169 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,
170 very large; >0.9 nearly perfect. The level of significance was set at $P < 0.05$.

171

172 **Results**

173 Descriptive data of the physical tests performed are presented in table 1. Table 2
174 shows the correlations between 1RM and power outputs in the HS and JS exercises with

175 the vertical jumps and 60-m sprinting times. For all power outputs significant correlations
176 were observed between the SJ and CMJ heights (varying between 0.58 and 0.82; $P < 0.05$),
177 while no significant correlations were found between 1RM and the vertical jumps. The
178 highest correlation values were observed between the different power outputs and 60-m
179 sprint time (varying between -0.80 and -0.91; $P < 0.05$), while the correlation between the
180 1RM with the same sprint distance was -0.63 ($P < 0.05$).

181

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

183

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

185

186 **Discussion**

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

193 The association between 1RM measures and performance has been extensively
194 described in many studies and within a recent review.²⁰ Wisloff et al.²³ reported
195 significant correlations between half-squat 1RM and sprint and jump performance (from
196 0.71 to 0.94) in professional soccer players. Similarly, McBride et al. (2009) found
197 significant relationships among a series of speed-tests (5, 10, and 40-yard) and back-squat
198 1RM, emphasizing the importance of normalizing 1RM values by the athletes' BM (as
199 relative values) to strengthen the associations between strength and performance

200 measures.¹⁹ In the present study, both 1RM and power outputs were expressed in relative
201 values, which likely contributed to increase the magnitude of the correlations observed
202 (Table 2). Nonetheless, as previously mentioned, these values were higher for power-
203 related variables and, notably, only these outputs were significantly associated with
204 vertical jump performance.

205 Requena et al.²⁴ reported similar results with well-trained sprinters, not finding
206 significant relationships between relative measures of squat 1RM and CMJ height. In
207 contrast, relative power production (in both squat and JS exercises) were found to be
208 moderately related to jump ability and maximal speed over different distances (from 20-
209 to 80-m). Accordingly, Loturco et al.²⁵ showed that both the MPP and the magnitude of
210 the load lifted at the optimum zone are highly correlated to sprint and jump capacities (r
211 ~ 0.80) in professional sprinters. These data are very similar to those described herein,
212 confirming the usefulness of the bar-power approach in assessing athletic performance,
213 especially in elite athletes. The opportunity to use ranges of loads which optimize the
214 force and velocity applied to the barbell at the same time^{15, 26} (instead of only considering
215 the maximum mass moved during a maximum effort [i.e., 1RM]) may better reflect the
216 abilities required in sport-tasks, where athletes are frequently required to move substantial
217 amounts of loads at high speeds (e.g., the BM during a vertical jump or maximal
218 sprints).^{25, 27, 28} Although this mechanical parameter does not represent “total power of
219 the system” (i.e., system-power)^{15, 16}, the bar-power output can be used not only to
220 monitor strength and power capacities, but also to discriminate athletes with different
221 performance levels and training backgrounds.²⁹

222 We recognize that the 1RM measurement is widely used to prescribe and control
223 training intensity, and there are several studies confirming its efficacy for such purposes.<sup>1,
224 ^{2, 13} Nevertheless, it is worth noting that, in terms of assessing athletes’ performance, the</sup>

225 relationship with specific physical capabilities (e.g., jumping and sprinting) is a relevant
226 criterion for test selection.^{19, 23, 25} Furthermore, there are potential risks involved in 1RM
227 testing,⁶⁻⁸ which compromises its frequent use in competitive sports, where the constant
228 evaluation of physical performance is of fundamental importance. More importantly,
229 there is a significant limitation in considering a given scalar variable (i.e., mass) as a
230 “strength measurement”.^{15, 26} In this context, it is critical to emphasize that the ability to
231 efficiently accelerate relative loads (and thus reach higher movement velocities) is a
232 selective factor in different sport disciplines.^{12, 25, 30, 31} The finding that the bar-power
233 output is more strongly associated with sport-performance than 1RM measures indicates
234 that this novel and alternative method might be an effective way to assess elite athletes.
235 Due to the high levels of precision and consistency presented by all power variables,
236 based on their preferences and possibilities (i.e., device features), practitioners can use
237 MP, MPP, or PP to estimate and define the optimum power zones, in both JS and HS
238 exercises.

239

240 **Practical Applications**

241 Frequent monitoring of athletes’ performance is essential in professional sports,
242 serving as a basis for adjusting training loads and methods, and evaluating individual
243 progress. Therefore, the use of applied, safe, and timesaving assessment tools becomes
244 crucial for the development of better and more effective training programs. The bar-power
245 approach is a practical training and testing strategy, which has been shown to be closely
246 related to actual performance^{25, 30, 31} and produce significant improvements in physical
247 abilities at both ends of the force-velocity curve.^{5, 8} In this study, we demonstrated that the
248 bar-power outputs are more strongly associated with speed and power performances in
249 elite athletes than 1RM measurements. With this in mind, coaches and researchers are

250 encouraged to assess the power production directly on the barbell to evaluate the strength-
251 power performance of their athletes. Despite the cross-sectional nature of our data, due to
252 the **large** correlations presented here, it is possible to infer that meaningful variations in
253 bar-power production may also represent substantial changes in athletic performance.
254 Further studies should be conducted to test the relationships between bar-power output
255 and alternative performance measures (e.g., repeated-sprint ability) and sport-tasks (e.g.,
256 change of direction tasks).

257

258 **Conclusions**

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

262

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370 **FIGURE CAPTIONS**

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

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

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

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

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

401 **Table 2.** Correlations (\pm 90% confidence intervals) between vertical jump performances and sprinting time with maximum dynamic strength in
 402 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)*

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