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Abstract

Askow, AT, Merrigan, JJ, Neddo, JM, Oliver, JM, Stone, JD, Jagim, AR, and Jones, MT. Effect of strength on velocity and power during back squat exercise in resistance-trained men and women. *J Strength Cond Res* 33(1): 1–7, 2019—The purpose was to examine load-velocity and load-power relationships of back squat in resistance-trained men ($n = 20$, 21.3 ± 1.4 years, 183.0 ± 8.0 cm, 82.6 ± 8.0 kg, 11.5 ± 5.0% total body fat) and women ($n = 18$; 20.0 ± 1.0 years; 166.5 ± 6.9 cm; 63.9 ± 7.9 kg, 20.3 ± 5.0% body fat). Body composition testing was performed followed by determination of back squat 1 repetition maximum (1RM). After at least 72 hours of recovery, subjects returned to the laboratory and completed 2 repetitions at each of 7 separate loads (30, 40, 50, 60, 70, 80, and 90% 1RM) in a random order. During each repetition, peak and average velocity and power were quantified using a commercially available linear position transducer. Men produced higher absolute peak and average power and velocity at all loads. When power output was normalized for body mass, significant differences remained. However, when normalizing for strength, no significant differences were observed between sexes. Furthermore, when subjects were subdivided into strong and weak groups, those above the median 1RM produced higher peak power, but only at loads greater than 60% 1RM. It was concluded that differences between men and women may be a result of strength rather than biological sex. Furthermore, training for maximal strength may be an appropriate method to augment maximal power output in those athletes who exhibit low levels of strength.

KEY WORDS kinetics, kinematics, sex differences

Introduction

The ability to generate high levels of power is critical to sport performance (14) and, as a result, has spurred numerous studies searching for ways to improve power production (26,33,34). One well-studied, widely used modality to augment power output is the use of free-weight resistance training (20,26). However, the most effective way to incorporate resistance training to increase power is debatable. The use of velocity-based training has been reported to enhance power performance and has gained popularity as a method from which to prescribe training loads and assess adaptations (12,13,25) as opposed to using traditional loading schemes based solely on percentages of the 1 repetition maximum (1RM). The velocity-based training method is effective due to a strong relationship between relative load and movement velocity (13); yet, further research is needed to clarify its application.

To date, the majority of research surrounding velocity and power profiling in athletes has been conducted in men with an absence of comparable data in women (19,37). This provides an exercise programming challenge for practitioners because many of the characteristics that are strongly associated with maximal power or speed have been shown to differ between men and women (19,37). Such disparities in strength and body size may lead to differences in performance characteristics (1,35,36). Indeed, recent reports suggest that men and women differ in the amount of power they can produce (10,38). However, research, in which power differences have been investigated, has not accounted for sex differences in strength and body size. Moreover, studies exploring the relationship of strength and size to performance outcomes between men and women are limited.

The present investigation evaluated the load-velocity and load-power relationships in the barbell back squat of resistance-trained (RT) men and women. The main objectives of this study were to determine whether or not men and women differ in power production and speed across a spectrum of loads, and to investigate the relationship

TABLE 1. Physical characteristics of resistance-trained subjects.*†

Variable	Men (n = 20)	Women (n = 18)	p
Age (yrs)	21.3 ± 1.4	19.8 ± 1.1	0.001
Height (cm)	183.0 ± 7.8	167.2 ± 7.3	0.0001
Body mass (kg)	82.6 ± 8.0	63.9 ± 7.9	0.0001
Training experience (yrs)	3.3 ± 1.3	2.8 ± 1.6	0.290
Body fat (%)	11.5 ± 5.0	20.3 ± 5.4	0.0001
$1RM_{BS}$ (kg)	147.0 ± 28.0	87.8 ± 12.1	0.0001
$1RM_{BS}$:FFM ratio	2.0 ± 0.4	1.7 ± 0.2	0.003

*$1RM_{BS}$ = 1 repetition maximum back squat; FFM: fat-free mass.
†Data are mean ± SD.

between strength, body size, and performance outcomes between men and women. It was hypothesized that men would be more powerful and faster than women across the load spectrum, that strength and body size would be strongly related to power and velocity outcomes, and that stronger individuals would be significantly faster and more powerful than weaker individuals.

METHODS

Experimental Approach to the Problem

The current investigation used a between-subject design to determine whether or not differences existed between RT men and women in regard to average power (AP), peak power (PP), average velocity (AV), and peak velocity (PV) when performing the back squat exercise across a range of loads (30–90% 1RM). After preliminary screening, subjects underwent a familiarization session and determination of a back squat 1

repetition maximum ($1RM_{BS}$). At least 72 hours after familiarization and $1RM_{BS}$ determination, subjects underwent the experimental testing procedure. Experimental testing procedures required subjects to perform at least 2 repetitions at each of 7 separate loads (i.e., 30, 40, 50, 60, 70, 80, and 90% 1RM), in a randomized order, corresponding to a relative percentage of each subject's $1RM_{BS}$. During each repetition, AP, PP, AV, and PV were measured using a commercially available linear position transducer (Tendo FitroDyne Unit; Tendo Sport Machines, Trencin, Slovak Republic). Subjects were asked to refrain from lower-body resistance training in the period between the 1RM testing day and the experimental testing day (~72 hours).

Subjects

Resistance-trained men (mean ± SD: n = 20, 21.3 ± 1.4 years, 183.0 ± 8.0 cm, 82.6 ± 8.0 kg, 11.5 ± 5.0% total body fat) and

TABLE 2. Bivariate correlations between body mass, maximal strength, and variables of interest.*

	30%	40%	50%	60%	70%	80%	90%
BM							
AV	0.555‡	0.593‡	0.506‡	0.555‡	0.500‡	0.402†	0.255
PV	0.424‡	0.363†	0.456‡	0.388†	0.236	0.240	0.252
AP	0.853‡	0.880‡	0.837‡	0.875‡	0.872‡	0.860‡	0.849‡
PP	0.767‡	0.864‡	0.866‡	0.873‡	0.866‡	0.886‡	0.880‡
$1RM_{BS}$							
AV	0.526‡	0.485‡	0.508‡	0.483‡	0.505‡	0.302	0.155
PV	0.322†	0.232	0.324†	0.243	0.129	0.059	0.043
AP	0.950‡	0.956‡	0.948‡	0.955‡	0.964‡	0.917‡	0.889‡
PP	0.887‡	0.918‡	0.937‡	0.918‡	0.905‡	0.906‡	0.878‡

*BM = body mass; AV = average velocity; PV = peak velocity; AP = average power; PP = peak power; $1RM_{BS}$ = 1 repetition maximum back squat.
†Significant at $p < 0.05$.
‡Significant at $p < 0.01$.

women ($n = 18$, 19.8 ± 1.1 years, 167.2 ± 7.3 cm, 63.9 ± 7.9 kg, $20.3 \pm 5.4\%$ total body fat) volunteered to participate in the study. Selection criteria included (a) men and women between the ages of 18 and 30 years; (b) previous or current collegiate/varsity sport participation; (c) the ability to squat 125% of their body mass; (d) currently training with at least one back squat session per week; (e) no lower-body musculoskeletal injury within 6 months; and (f) no current nutritional or ergogenic
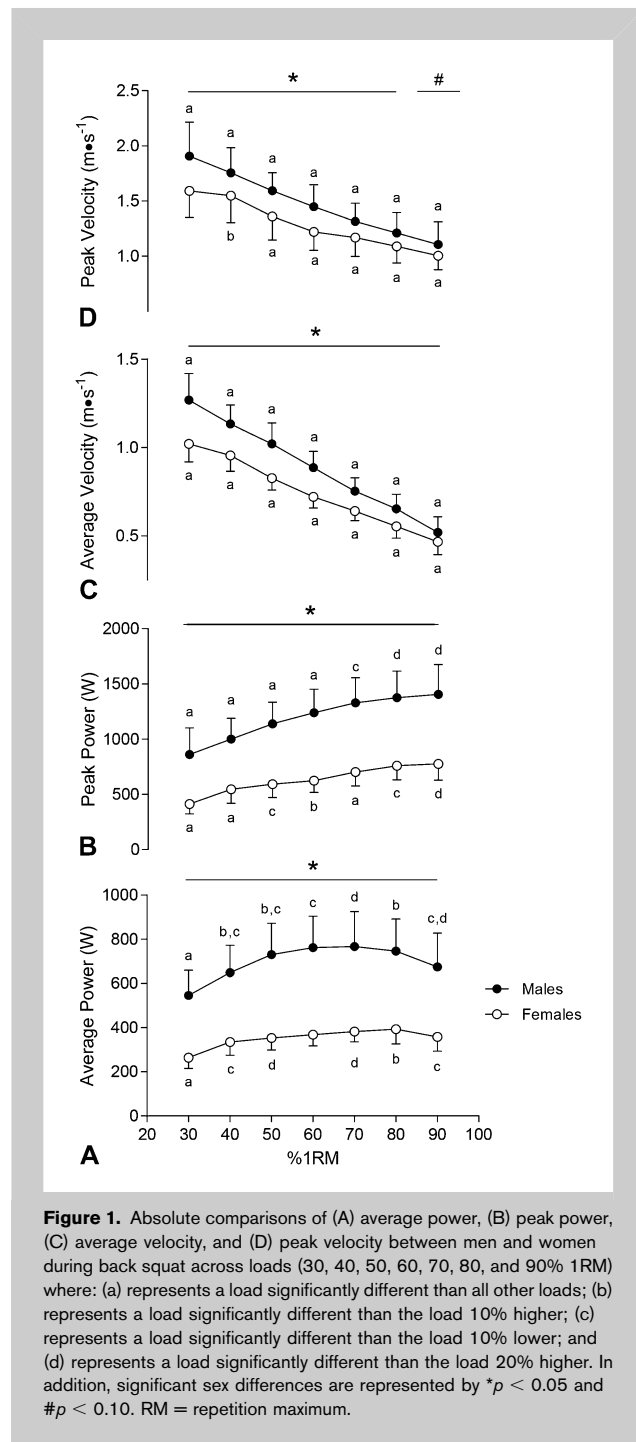
supplement use. Subjects meeting all criteria for participation were informed of the experimental procedures and risks associated with participation and signed an informed consent document. All procedures involving human subjects were approved by the George Mason University Institutional Review Board. Physical characteristics for the subjects ($n = 38$) are presented in Table 1.

Procedures

Body Composition. At a minimum, subjects were instructed to refrain from exercise, eating, and drinking for at least 2 hours before testing. However, the majority of testing was conducted in the early morning after an overnight fast. On arrival to the laboratory, height and body mass were recorded to the nearest 0.01 cm and 0.02 kg, respectively, using a stadiometer (Detecto, Webb City, MO, USA) and high-precision digital scale (BOD POD; COSMED USA, Inc., Concord, CA, USA) calibrated according to manufacturer guidelines with subject's bare foot. Body composition was then assessed using air-displacement plethysmography (BOD POD, model 2000A; COSMED USA, Inc), which has been validated and highly correlated with hydrostatic weighing (4). Fat and fat-free mass values were determined based on the body densities obtained. Before each testing session, calibration procedures were completed according to the manufacturer guidelines using an empty chamber and a calibrating cylinder of a standard volume (49.55 L). Subjects were instructed to wear a formfitting sports bra (women), spandex shorts, and swim cap, and remove all jewelry, in accordance with standard operating procedures, to reduce air displacement. A trained technician performed BOD POD testing. Test-to-test reliability of performing this body composition assessment in our laboratory has yielded high reliability for body mass ($r = 1.0$), body fat percent ($r = 0.997$), and fat-free mass ($r = 1.0$) (8). Previous studies indicate air-displacement plethysmography to be an accurate and reliable means to assess changes in body composition (9,27,31).

Warm-up. After body composition assessment, subjects completed a supervised, standardized, 10-minute warm-up to enhance safety and reduce the risk of injury. The warm-up consisted of continuous rowing for 4 minutes on a rowing ergometer, which was immediately followed by 12 whole-body dynamic flexibility exercises designed to actively move the ankle, knee, hip, and shoulder joints through a complete range of motion.

One Repetition Maximum Testing (1RM). After the 10-minute dynamic warm-up, $1RM_{BS}$ was assessed using a protocol previously described in Oliver et al. (33). Subjects performed the following warm-up sets at percentages of their estimated 1 repetition maximum (e1RM): 1 set of 3 repetitions followed by 45 seconds' rest ($1 \times 3 \times 50\%$ e1RM 45 seconds' rest); $1 \times 3 \times 60\%$ e1RM 45 seconds' rest; $2 \times 2 \times 70\%$ e1RM 60 seconds' rest; $1 \times 1 \times 80\%$ e1RM 120 seconds' rest; $1 \times 1 \times 90\%$ e1RM 150 seconds' rest; $1 \times 1 \times 95\%$
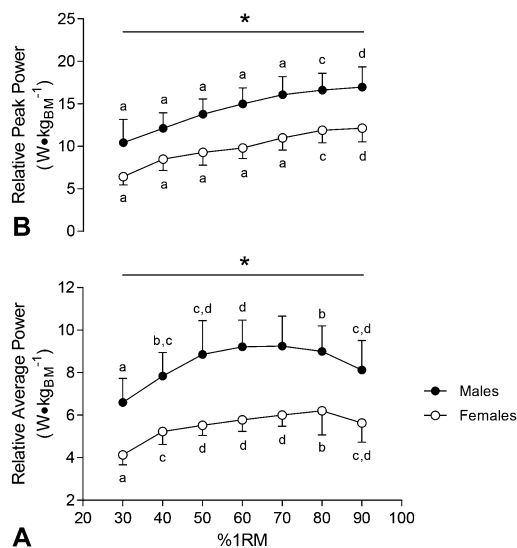

Figure 1. Absolute comparisons of (A) average power, (B) peak power, (C) average velocity, and (D) peak velocity between men and women during back squat across loads (30, 40, 50, 60, 70, 80, and 90% 1RM) where: (a) represents a load significantly different than all other loads; (b) represents a load significantly different than the load 10% higher; (c) represents a load significantly different than the load 10% lower; and (d) represents a load significantly different than the load 20% higher. In addition, significant sex differences are represented by *$p < 0.05$ and #$p < 0.10$. RM = repetition maximum.

Figure 2. Normalized to body mass (BM) comparisons of A) average power and B) peak power between men and women during back squat across loads (30, 40, 50, 60, 70, 80, 90% 1RM) where: a, represents a load significantly different than all other loads; b, represents a load significantly different than the load 10% higher; c, represents a load significantly different than the load 10% lower; d, represents a load significantly different than the load 20% higher. Additionally, significant sex differences are represented by *($p < 0.05$) and #($p < 0.10$).

e1RM 180 seconds' rest; 100% or greater for 1RM attempts. During testing, subjects were instructed to move the bar as explosively as possible in an attempt to achieve maximal power output (3). Multiple 1RM attempts were permitted and assessment concluded when subjects failed to complete a successful lift within 2 attempts. Weightlifting belts were allowed based on subject preference. Standard Olympic-style barbells and barbell weights were used (Power Lift, Jefferson, IA, USA). A Certified Strength and Conditioning Specialist (NSCA-CSCS) supervised all testing sessions.

Experimental Testing Session. The experimental testing session took place at least 72 hours after familiarization and 1RM$_{BS}$ testing. During this session, subjects completed the same dynamic warm-up as the familiarization session followed by a standardized barbell squat warm-up consisting of 1 set of 5 repetitions at both 40 and 60% of 1RM$_{BS}$, 1 set of 2 repetitions at 70% of 1RM$_{BS}$, and 1 single repetition at 80% of 1RM$_{BS}$. Next, in a randomized fashion, subjects completed a single repetition at 7 intensities: 30, 40, 50, 60, 70, 80, and 90% of 1RM$_{BS}$. Subjects were verbally instructed to perform each repetition "as explosively as possible" before the initiation of the attempt. A timed rest of 120 seconds of rest was taken between each repetition.

Linear Position Transducer. Peak power and AP as well as PV and AV were recorded for each repetition attempt using a commercially available linear position transducer (Tendo FitroDyne; Tendo Sports Machines) attached to the right side of the bar in accordance with the manufacturer's instruction. The reliability of the selected linear position transducer unit has been previously reported in the jump squat and full back squat (18). Furthermore, the validity and reliability of this tool for AV, PV, AP, and PP have been previously reported for back squat (0.922–0.982) and bench press (0.977–0.988) exercises (11).
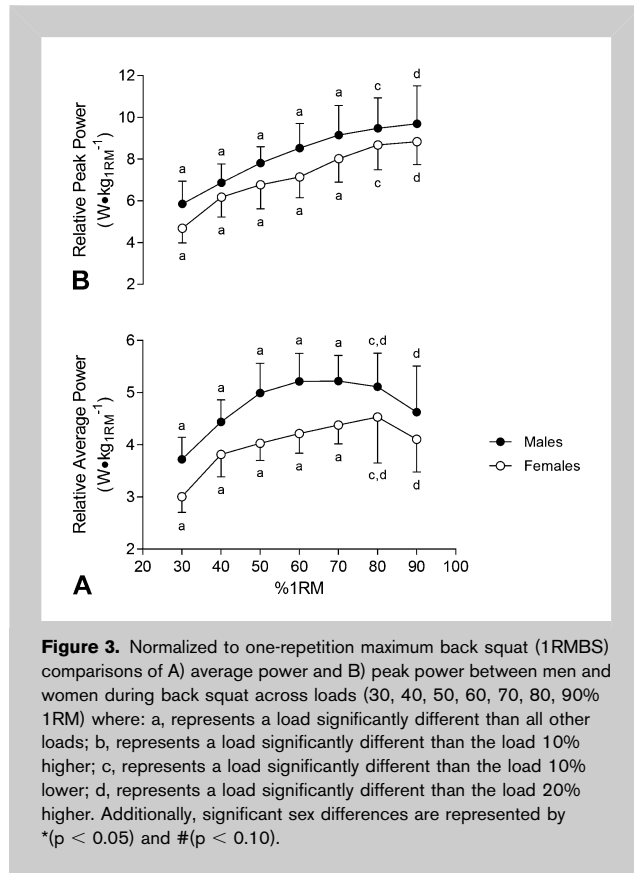
Statistical Analyses

Descriptive data (mean $\pm$ *SD*) were computed from the highest value from each intensity for PP, AP, PV, and AV. Data were analyzed using 3 separate models. First, to observe the absolute differences between men and women, velocity and power data were analyzed using a mixed-model (sex (2) $\times$ load (7) $\times$ strength (2)) repeated-measures analysis of variance (ANOVA). After this analysis, data were normalized to body mass and 1RM$_{BS}$ to observe the differences between men and women relative to body size and strength and analyzed using the same (2 $\times$ 7 $\times$ 2) mixed-model repeated-measures ANOVA. In these models, participants were separated into 2 groups (strong vs. weak) based on possessing a 1RM$_{BS}$ above or below the median 1RM$_{BS}$ within their respective sex. Least squares differences post hoc analyses were performed when a significant finding ($p \leq 0.05$) or trend ($p \leq 0.10$) was identified. Bivariate (Pearson) correlations were computed to determine significant relationships among variables of interest within pooled data. Cohen's *d* effect sizes were calculated for significant interactions. All analyses were conducted using the Statistical Package for the Social Sciences (SPSS, Version 24; IBM, Somers, NY, USA).

RESULTS

Baseline physical characteristics for subjects are presented in Table 1. Within- and between-sex differences in absolute PP, PV, AP, and AV are presented in Figures 1–3, respectively. Bivariate correlations between body mass, 1RM$_{BS}$, and variables of interest are presented in Table 2. Correlations between 1RM$_{BS}$ and power outcomes (PP and AP) were very strong ($r = 0.887$–0.964, $p < 0.01$). However, correlations between 1RM$_{BS}$ and velocity outcomes (PV and AV) were weaker and more variable. These correlations ranged from nonsignificant and very weak coefficients ($r = 0.043$, $p > 0.05$) to significant and moderate coefficients ($r = 0.526$, $p < 0.01$). The same trend can be seen for correlations between body mass and variables of interest (PP, AP, PV, and AV) (Table 2).

When examining the absolute values for each outcome variable, a main effect of INTENSITY was observed for each of the outcome variables of interest (PP, PV, AP, and AV; all $p < 0.001$). A significant INTENSITY x SEX interaction was

Figure 3. Normalized to one-repetition maximum back squat (1RMBS) comparisons of A) average power and B) peak power between men and women during back squat across loads (30, 40, 50, 60, 70, 80, 90% 1RM) where: a, represents a load significantly different than all other loads; b, represents a load significantly different than the load 10% higher; c, represents a load significantly different than the load 10% lower; d, represents a load significantly different than the load 20% higher. Additionally, significant sex differences are represented by *(p < 0.05) and #(p < 0.10).

also observed for each of the outcome variables of interest (PP, $p < 0.001$; PV, $p = 0.013$; AP, $p < 0.001$; and AV, $p < 0.001$). However, no interaction was observed with STRENGTH in any of the outcome variables (PP, $p = 0.818$; PV, $p = 0.169$; AP, $p = 0.366$; and AV, $p = 0.205$). Men produced higher absolute PP ($d = 2.36$, large), AP ($d = 2.87$, large), PV ($d = 0.61$, moderate), and AV ($d = 0.62$, moderate) than women across all loads (Figure 1). Peak power increased and velocity (both PV and AV) decreased, almost linearly, across all intensities, irrespective of sex (Figure 1B–D). For men, AP increased up to 60% 1RM$_{BS}$, before a plateau was observed, followed by a decrease at 90% 1RM$_{BS}$. Although a similar plateau was observed in women, fewer significant differences were observed among intensities (Figure 1A).

When normalized for body mass, a main effect of INTENSITY was observed for PP and AP ($p < 0.001$) and a significant INTENSITY × SEX interaction was observed for AP ($p = 0.006$; Figure 2A) and PP ($p = 0.051$; Figure 2B). No interaction with STRENGTH was observed for PP or AP ($p = 0.136$ and $p = 0.305$, respectively). Men produced significantly higher PP ($d = 1.67$, large) and AP ($d = 2.25$, large) than women at all loads (all $p < 0.001$; Figure 2). For both men and women, PP increased in a linear fashion across all loads. Similar to that observed in absolute AP,

AP relative to body mass increased up to 60% 1RM$_{BS}$, when a plateau was observed, then decreasing from 80 to 90% 1RM$_{BS}$. For women, a similar trend was observed with AP increasing to 70% 1RM$_{BS}$ and decreasing from 80 to 90% 1RM$_{BS}$, again with fewer differences among intensities.

When normalized for 1RM$_{BS}$ (Figure 3), a significant main effect of INTENSITY was observed for PP and AP (both $p = 0.001$; Figure 3) with a significant INTENSITY × STRONG interaction for PP ($p = 0.003$) but not AP ($p = 0.067$), although the latter approached significance. No significant INTENSITY × SEX interaction was observed for PP ($p = 0.242$) or AP ($p = 0.099$). Regardless of sex, those above the median 1RM$_{BS}$ produced lower PP, but only at higher loads: 60% 1RM$_{BS}$ ($p = 0.047$, $d = 0.63$, moderate), 70% 1RM$_{BS}$ ($p = 0.087$, $d = 0.59$, small), 80% 1RM$_{BS}$ ($p = 0.030$, $d = 0.76$, moderate), and 90% 1RM$_{BS}$ ($p = 0.069$, $d = 0.64$, moderate).

DISCUSSION

The purpose of the current study was to examine sex differences in PP, AP, PV, and AV across a spectrum of loads (30, 40, 50, 60, 70, 80, and 90% 1RM$_{BS}$) in the freeform back squat exercise. The main findings were that men produced higher absolute PP, AP, PV, and AV across all loads used in this experiment (Figure 1). Sex differences in PP and AP seemed to be strongly related to body mass and 1RM$_{BS}$, whereas differences in PV and AV showed only low to moderate correlations with BW and 1RM$_{BS}$ (Table 2). Further support of the strong association between power output and 1RM$_{BS}$ can be seen when data are normalized to 1RM$_{BS}$ whereby the differences between men and women subside (Figure 3). The moderate significant relationships between velocity and both BW and 1RM$_{BS}$ were observed at lower intensities, whereas higher intensities showed nonsignificant relationships. These data indicate that strength and body mass may contribute to differences in velocity at lower loads, but not when intensity is >70% 1RM$_{BS}$.

The current finding of sex differences in power during the back squat is in support of previously published work, which has demonstrated that men produce greater power outputs in weightlifting exercises (10), the deadlift (19), the Wingate (38), and other explosive exercises (37). In a similar population, Jones et al. (19) demonstrated that men were significantly faster and more powerful during the barbell deadlift across a range of loads (30, 60, and 90% 1RM). Furthermore, Thomas et al. (37) reported that men were significantly more powerful during the squat jump and high pull at loads ranging from 30 to 70% 1RM. In both investigations, authors reported that men had higher 1RM in the exercise being tested, which supports the finding that strength is strongly associated with power-production capability.

In the current investigation, men produced greater power than women at all loads. When normalized for body mass, these differences subsisted for PP and AP, evidenced by a significant LOAD × SEX interaction. However, when

power output data were normalized to $1RM_{BS}$, no differences were observed in PP or AP. This finding supports previous literature that reported maximal power production to be strongly associated with maximal strength (1,3,5,16,21,23,24,26,28,35,36). Evidence of said relationship has been reported in cross-sectional studies (1,5,21,23,35,36) where stronger athletes have higher power outputs than weaker athletes and in longitudinal studies where an increase in maximal power production is observed concomitantly with an increase in maximal strength (3,16,24,26,28).

Although strength is an important determinant of power production, it is unlikely that all athletes should focus on maximal strength training as a means to augment power production. In fact, those who possess a high capacity for maximal force production may experience diminished power adaptation after a period of heavy strength training due to a reduced magnitude of strength gains experienced compared to those with a lower capacity for force production (7,22). Furthermore, adaptations in those individuals after strength training will likely be velocity-specific in that the high forces and low velocities will be affected to a greater degree than low forces and high velocities (15,17,29,30). Velocity-based training has been shown as an effective alternative to traditional loading paradigms (13,16), and has been suggested as an appropriate method to predict 1RM or monitor training load (12,13). In the current study, the strongest correlations between 1RM and velocity occurred at loads less than or equal to 70% 1RM. The higher 1RM of men compared with women is consistent with previous work in this area (19,37), and may in part explain the sex differences in velocity. Cumulatively, these findings suggest that weaker individuals may benefit from a period of maximal strength training to increase velocity-production capabilities.

An important factor to consider when comparing velocity or power outcome variables from different investigations is the methodology used to quantify collected data. In the current investigation, a single commercially available linear position transducer was used, which has previously been established as a reliable and valid method of kinetic and kinematic data collection (18). However, the use of a single linear position transducer has been questioned (6). Although utilization of a force platform in conjunction with multiple linear position transducers is considered the criterion method, these systems are cost-prohibitive and less common in the practitioner setting. By contrast, a single linear position transducer is relatively inexpensive and largely accessible to strength and conditioning practitioners, who widely use this tool as a method to track adaptations and prescribe training intensities (2,32).

The current investigation sought to examine differences in back squat performance across a range of loads in RT men and women. The main finding was that men produce significantly higher peak and average power and velocity across all relative loads in the back squat. Although correlations indicate that both body mass and maximal strength are highly associated with power production at all loads, normalization of data to body mass resulted in the subsistence of significant differences between men and women, whereas the normalization to $1RM_{BS}$ diminished such differences. In all, these findings suggest that $1RM_{BS}$ is an important determinant of an athlete's power-production capability. The present findings suggest that differences in maximal power-production capability can be attributed to maximal strength capacity rather than biological sex.

PRACTICAL APPLICATIONS

These data suggest that differences in power production are strongly related to maximal strength, irrespective of sex. Therefore, weaker men and women may benefit more from maximal strength training than stronger men and women, who are likely closer to their maximal strength level. Furthermore, the finding that strength is an important determinant of power production may offer utility for strength and conditioning practitioners. Given that power production is highly associated with athletic success (division of play and starting status), weaker individuals may benefit most from training to increase overall strength to augment power-production capabilities.

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