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Maximal power production as a function of sex and training status

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ABSTRACT: Maximal muscular power is achieved at lower percentages of maximal strength (1RM); however, this notion has not been elucidated based on sex or training status. Therefore, the purpose of this investigation was to examine the influence of sex and training status on maximal power production. Sixty men and women (resistance trained or untrained) completed 1RM testing for the two-leg press (2LP) and bench press (BP). Participants then returned to perform single repetitions at 20, 30, 40, 50, 60, 70 and 80% of their 1RM to determine muscular power. Factorial analyses determined significant interactions (training status by sex by intensity) for the BP ($F=35.6$, $p<0.001$) and 2LP ($F=8.2$, $p<0.001$). Subsequent analyses indicated that during the BP trained men produce maximal power between 30-40% 1RM compared to untrained men at 60-70% 1RM. Trained women produced maximal power at 50% 1RM compared to untrained women at 60-70% 1RM. During the 2LP, trained men produced maximal power at 40% 1RM compared to untrained men at 60% 1RM. Trained women produced maximal power at 50% 1RM compared to 60-70% 1RM in untrained women. These data suggest that resistance trained individuals and men display maximal power at a lower relative intensity than untrained individuals and women.

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INTRODUCTION

Muscular power is an important physical characteristic for several populations such as athletes or elderly for different circumstances, including sport performance or fall prevention. Although the requirement of muscular power in various populations has been documented, previous literature makes the application difficult due to inconsistent results. For example, previous literature has suggested that maximal power output can be achieved when performing exercises between 10-80% of one-repetition maximum (1RM) [1–3]. Additionally, these suggestions must be applied with caution as the exercise and individual performing the exercise both contribute in determining the intensity that maximal output is produced [1–8].

Due to the importance of muscular power in successful sport performance, most of the previous literature aims to determine maximal power loading strategies for trained individuals. However, very little research has been conducted to illuminate the differences between trained and untrained individuals in regard to maximal power output. Moreover, the previous literature examining the differences in training status has revealed conflicting results. For example, Thomas et al. [6] reported that untrained women produced maximum power at 56-78% of double leg press 1RM, which is a much higher intensity than recommended for trained individuals (~30% 1RM) [1]. Additionally, Baker et al. [4], reported that an experienced resistance training group displayed maximal power output at a lower relative intensity of their 1RM (51.1% 1RM) when compared to a less experienced group (54.9% 1RM). In contrast to the aforementioned findings, additional investigations have suggested that training status does not impact the optimal load for power output [9,10] even in the presence of significant strength differences [11]. Thus, the influence of training status on maximal power output remains elusive.

Additionally, a dearth of literature exists comparing the intensity needed to evoke maximal power output between men and women.

According to the National Strength and Conditioning Association and American College of Sports Medicine, loads between 30-60% and 0-60% of 1RM, should be employed when training for muscular power. Moreover, recent meta-analyses indicate that power output is exercise specific for both the upper and lower body [7,8]. Despite differences in skeletal muscle quantity and function being observed, neither organization alludes to potential variations between men and women [12–14]. Unfortunately, the admirable work from Soriano et al. [7,8] examined investigations including men and trained participants, thus limiting the application for women and untrained individuals. Previous research has yielded conflicting results, such that maximal power output is achieved at different or similar intensities between men and women [1,15]. Thus, further investigation is necessary to illuminate the influence of sex on producing maximal power. With previous research suggesting that sex and training status influence maximal power output, the need to evaluate their influence is warranted. Therefore, the purpose of this investigation was to examine the influence that sex has on producing maximal power output during an upper and lower body exercise, and to evaluate the influence of training status on maximal power output.

MATERIALS AND METHODS

Participants

Sixty (N=60) men and women volunteered to participate in this study. Thirty participants (15 men and 15 women) had previous resistance training experience, while thirty additional participants (15 men and 15 women) reported no previous consistent resistance training experience. Training experience was determined through questions from a health status questionnaire (HSQ) completed during visit 1. Participants classified as 'trained' had performed resistance training at least three days a week for the previous three years. During data collection, participants were requested to refrain from performing any type of resistance exercise within 72 hours before completing visits 2 (1RM testing) and 3 (power testing). Additionally, to remain consistent and to exclude any possible contribution, the use of resistance training gear (i.e. wrist wraps, lifting belt, knee sleeves, etc.) during testing was not permitted. This study was approved by a university review board and prior to participating in the study each subject signed an informed written consent form and were made aware that participation was voluntary and could withdraw at any time without consequences.

Familiarization of Bench Press and Two-Leg Press

The initial visit for each subject required the completion of an informed consent form, PAR-Q, and HSQ. Following the completion of paperwork, each subject was verbally instructed and provided demonstration on how to execute the barbell bench press (BP) and horizontal two-leg press (2LP). After the investigator instruction, each subject performed 5-10 repetitions, of each movement, with relatively light loads to become familiar with both of the movements. Each subject was allowed as many repetitions as necessary to become familiar with the equipment, and each subject was required to perform the familiarization trial.

Bench Press and Two-Leg Press Testing

The second visit encompassed 1RM testing for the BP and the 2LP. The testing order for each subject was randomized prior to arrival. Subject height and weight were both recorded using a mounted stadiometer and a digital scale, respectively. Following anthropometric assessments, each subject performed a five-minute light intensity (<50W) cycling warm up. Once the warm-up was completed, participants performed the first of the two exercises. Each subject performed the 1RM testing for each exercise in the following manner. First, participants performed 5-6 repetitions with a load approximately equal to 50% of their estimated maximal strength. Following a 1-minute rest, participants then completed 3-4 repetitions with a load approximately equal to 75% of their estimated 1RM. Following a 2-minute rest, the exercise load was increased so a 1RM was achieved within 5 additional attempts. Each attempt during this portion of the testing was separated by 2-4 minutes of rest. Each 1RM test was completed under the supervision of a certified strength and conditioning specialist. Following the first 1RM test subjects were provided with ten minutes seated rest before beginning the second 1RM test.

Two-Leg Press. The 2LP was performed using a horizontal CYBEX machine (Cybex International, Medway, MA). The machine comes equipped with 500 pounds of total resistance with an additional 17 pounds of stackable weight that can be added on to the top of the weight stack. If any subject was able to perform the 2LP with a weight greater than 517 pounds, the subject was instructed to perform the next set of repetitions to volitional fatigue. The total amount of repetitions performed with 517 pounds was then inputted into a 1RM formula [16] and the determined value served as the participants 1RM. When performing the 2LP assessment, participants started with their feet hip width apart, knees flexed at 90 degrees, and were instructed to push the weight until knee extension was approached.

Bench Press. BP testing was performed using a flat bench and barbell. When performing the BP assessment, participants un-racked the barbell and lowered the bar to the chest, and were instructed to push once the barbell reached their chest. If a subject tried to bounce the bar off their chest, the repetition was discarded and re-recorded.

Power and Velocity Testing

Maximal peak power was measured using a Tendo FitroDyne power and speed analyzer (TFDA; Tendo Weightlifting Analyzer, Slovak Republic). Following a minimum of 48 hours after establishing the 1RM, participants returned to the laboratory for maximal power testing and were provided the option to return a minimum of 7 days later to perform additional power and velocity measures for reliability analyses. Following a five-minute light intensity (<50W) cycling warm up procedure, each subject performed one repetition at intensities of 20, 30, 40, 50, 60, 70, and 80% of 1RM. In attempt to avoid the adverse effects of fatigue on testing, repetition order was randomized for each subject and determined before subject arrival. After each repetition, participants were given two minutes of rest before performing subsequent repetitions and each repetition was performed under the supervision of a certified strength and conditioning specialist.

During the 2LP testing, the TFDA sensor was placed directly beneath the weight stack and the velcro strap was fastened to the weight stack. When performing the 2LP power assessment, participants started with their feet hip width apart, knees flexed at 90 degrees, and were instructed to push the weight with as much force and as fast as possible. When measuring BP power, the TFDA sensor was placed directly below the barbell trajectory location with the velcro strap fastened toward the end of the barbell in accordance with manufacturer's manual. When performing the BP power assessment, participants un-racked the barbell, lowered the bar to the chest, and were instructed to push with as much force and as fast as possible once the barbell reached the chest. If a subject tried to bounce the bar off their chest, the repetition was discarded and re-recorded. Previous data from our lab indicate that the TFDA displays moderate to excellent ICC values from 0.77-0.98.

Statistical Analyses

Two mixed-model analyses of variance (ANOVAs) were used to evaluate statistical differences. The between factors were sex and training status (trained or untrained) and the within factor was intensity (20, 30, 40, 50, 60, 70, and 80% of 1RM). If a significant F score was observed, a Bonferroni post hoc test was utilized for pairwise comparisons. Effect sizes (ES) were calculated to determine the practical significance between relative loads and characterized according to Cohen [17]. Reliability analyses of the power measured from the TFDA was examined using intraclass correlation coefficients (ICC) and standard error of the measurement (SEM). The alpha level was set at 0.05 for all analyses and data are presented as mean ± SD. Normality of data was confirmed using the Kolmogorov-Smirnov test and equality of variances was verified by the Levene test. Statistical analyses were conducted using SPSS statistical software package V.23.0 (SPSS Inc., Chicago, IL, USA). Sample size was calculated a priori which indicated a sample size of forty participants to achieve a statistical power of 0.80. In attempt to maintain statistical power in regard to subject compliance, fifteen participants for each group were recruited.

RESULTS

Bench Press

BP 1RM values for each group are presented in Table 1. Reliability analyses indicated that BP power displayed moderate to high reliability (ICC: .77-.91) while displaying marginal error (SEM: 3-7.2%). Factorial analysis revealed a significant ($F=35.6$, $p<0.001$, η^2: 0.81) three-way (training status by sex by intensity) interaction. Additionally, main effects were present for intensity ($F=47.9$, $p<0.001$, η^2: 0.85), training status ($F=45.8$, $p<0.001$, η^2: 0.45), and sex ($F=165.9$, $p<0.001$, η^2: 0.75) as were interactions for intensity by training status ($F=69.4$, $p<0.001$, η^2: 0.89) and intensity by sex ($F=25.2$, $p<0.001$, η^2: 0.75).

Subsequent analyses indicated that resistance trained individuals displayed significantly greater power during the BP at intensities of 20% ($p<0.001$, ES: 0.90), 30% ($p<0.001$, ES: 1.38), 40% ($p<0.001$, ES: 1.36), and 50% ($p<0.001$, ES: 1.39). However, when performing the BP at intensities of 60% ($p=0.25$, ES: 0.49), 70% ($p=0.17$, ES: 0.25), or 80% 1RM ($p=0.31$, ES: 0.54) no statistical mean differences were revealed for training status. Resistance trained women achieved maximal power output at 50% 1RM which was significantly different from 20% ($p<0.001$, ES: 1.8), 30% ($p<0.001$, ES: 1.22), 40% ($p<0.001$, ES: 0.86), 60% ($p<0.001$, ES: 1.12), 70% ($p<0.001$, ES: 1.26) and 80% 1RM ($p<0.001$, ES: 1.36). Untrained women produced maximal power

TABLE 1. Participant anthropometric absolute, and relative strength values.

	Men		Women	
	Trained (n=15)	**Untrained (n=15)**	**Trained (n=15)**	**Untrained (n=15)**
Age (y)	21.2±1.3	23.3±2.5	21±1.8	23.6±2.3
Height (cm)	183.9±5.2^{c}	183.1±9.2^{c}	174.19±7.1	168.8±7.5
Weight (kg)	89.3±8.7^{c}	86.1±10.7^{c}	70.9±10.2	67.3±7.7
BP 1RM (kg)	116.9±18.7^{a,c}	72.1±11.7^{c}	52.6±16.6^{a}	29.4±5.0
Relative BP	2.9±0.4^{a}	1.9±0.4	1.6±0.4^{a}	1.0±0.2
2LP 1RM (kg)	226.0±20.1^{b,c}	194.5±32.6^{c}	181.4±30.6^{a}	133.3±18.9
Relative 2LP	5.8±0.7^{a}	5.1±1.4	5.7±0.8^{a}	4.4±0.6

Results are expressed as mean ± SD. BP – bench press; 2LP – two-leg press; 1RM – one-repetition maximum. Significant training status difference within sexes $p<0.001^{a}$; $p<0.01^{b}$. Significant difference between sexes $p<0.001^{c}$.

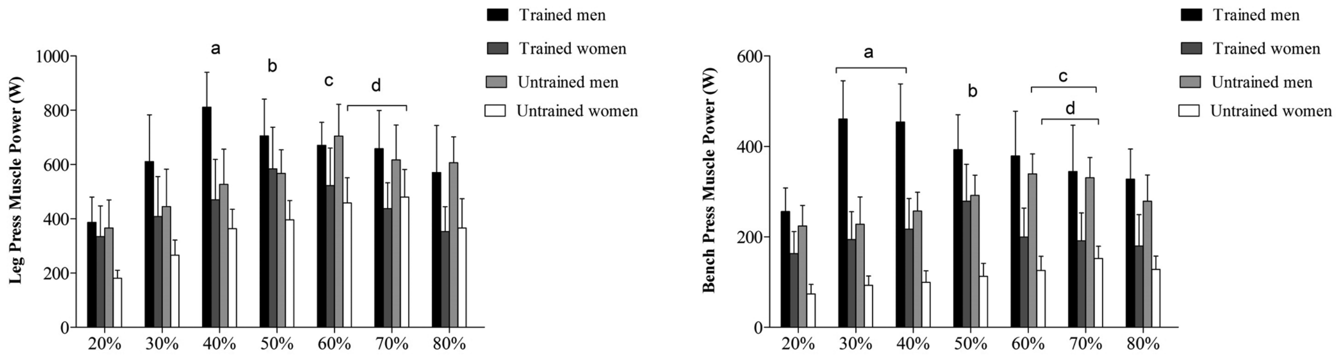

FIGURE 1. Peak power output (W ± SE) achieved at each intensity for subjects during the bench press and two-leg press across the spectrum of loads. Intensity that maximal power was produced for trained men – a; trained women – b; untrained men – c; untrained women – d.

at 70% 1RM, which was not significantly different from 60% (p=0.23, ES: 0.39), but significantly different from 20% (p<0.001, ES: 3.33) 30% (p<0.001, ES: 2.55), 40% (p<0.001, ES: 2.08), 50% (p<0.001, ES: 1.45) and 80% 1RM (p<0.001, ES: 0.88) Resistance trained men produced maximal power at 30% 1RM, which was not significantly different from 40% (p=0.82, ES: 0.08), but significantly greater than 20% (p<0.001, ES: 3.01) 50% (p<0.001, ES: 0.86), 60% (p<0.001, ES: 0.92), 70% (p<0.001, ES: 1.28) and 80% 1RM (p<0.001, ES: 1.82). Untrained men produced maximal power at 60%, which was not different from 70% (p=0.61, ES: 0.20), but significantly different from 20% (p<0.001, ES: 2.66), 30% (p<0.001, ES: 2.19), 40% (p<0.001, ES: 1.99), 50% (p<0.001, ES: 1.11) and 80% 1RM (p<0.001, ES: 1.21). Lastly, at each of the intensities resistance trained and untrained men produced significantly greater power (p<0.001) when compared to resistance trained and untrained women, respectively.

Two-Leg Press

2LP 1RM values for each group are reported in Table 1. Reliability analyses indicated that 2LP power possessed moderate to high reliability (ICC: .77-.98) while displaying marginal error (SEM: 2.8-7.1%). The factorial analysis revealed a significant (F=8.2, p<0.001, η^2: 0.13) three-way (training status by sex by intensity) interaction. Additionally, main effects were present for training intensity (F=103.9, p<0.001, η^2: 0.65), sex (F=60.5, p<0.001, η^2: 0.52), and training status (F=11.32, p<0.001, η^2: 0.17) as were significant interactions were present for intensity by training status (F=22.9, p<0.001, ^{2}: 0.29) and intensity by sex (F=6.2, p<0.001, η^2: 0.10).

Subsequent analyses indicated that resistance trained men and women displayed significantly greater power at 30% (p<0.001, ES: 1.10) 40% (p<0.001, ES: 2.29) and 50% 1RM (p<0.001, ES: 1.26) and 20% (p<0.001, ES: 0.50), 30% (p<0.001, ES: 2.21), 40% (p<0.001, ES: 0.95) and 50% 1RM (p<0.001, ES: 1.63), respectively when compared to untrained men and women. Resistance trained women displayed maximal power output at 50% 1RM, which was significantly greater than 20% (p<0.001, ES: 1.92), 30% (p<0.001, ES: 1.21), 40% (p<0.001, ES: 0.78) 60% (p<0.001, ES: 0.44), 70% (p<0.001, ES: 1.19) and 80% 1RM (p<0.001, ES: 1.90). Untrained women displayed maximal power at 70% 1RM, which was significantly greater than 20% (p<0.001, ES: 2.49), 30% (p<0.001, ES: 2.26), 40% (p<0.001, ES: 2.71), 50% (p<0.001, ES: 0.99) and 80% 1RM (p<0.001, ES: 1.12), but not 60% 1RM (p=0.57, ES: 0.23). Resistance trained men achieved maximal power at 40% 1RM, which was significantly greater than 20% (p<0.001, ES: 3.92), 30% (p<0.001, ES: 1.37), 50% (p<0.001, ES: 0.83), 60% (p<0.001, ES: 1.34), 70% (p<0.001, ES: 1.18) and 80% 1RM (p<0.001, ES: 1.64). Untrained men displayed maximal power at 60% 1RM, which was significantly greater than 20% (p<0.001, ES: 3.18), 30% (p<0.001, ES: 2.10), 40% (p<0.001, ES: 1.41), 50% (p<0.001, ES: 1.38), 70% (p<0.001, ES: 0.74) and 80% 1RM (p<0.001, ES: 0.95). Untrained men displayed significantly greater power (p<0.001) at each intensity during the 2LP when compared to untrained women. Trained men produced significantly greater power output (p<0.001) at 30-80% 1RM when compared to trained women.

DISCUSSION

The primary findings of this investigation indicate that i) the intensity at which maximal power is produced differs between resistance trained men and resistance trained women; ii) the intensity at which maximal power is produced differs between resistance trained individuals and those who are not resistance trained and iii) that maximal power output is produced at similar intensities between upper and lower body compound movements. The novelty of this study, which contributes to the current body of literature by including a sex and training status comparison, suggests that maximal power output is directly affected by an individual's training status and sex (Figure 1).

Our findings indicate that resistance trained men produce maximal power at a lower relative intensity than women. However, the influence of sex appears to be marginal for untrained individuals since maximal power was produced at 60 and 70% 1RM for untrained men and women during both the BP and 2LP. Currently, there is a dearth of literature examining the influence of sex on the intensity that maximal power output is achieved . Thomas et al. [1] examined trained men and women and reported that maximal power output was displayed at different intensities for men and women during the BP throw and squat jump but not the high pull. Regarding the BP throw and squat jump, which agrees with the present data, the authors reported that men produced maximal power at a lower relative intensity than women for both exercises. However, in contrast to the current findings, and those of Thomas et al. [1] regarding the BP throw and squat jump, Jones and colleagues [15] examined maximal power output during the deadlift at intensities of 30, 60, and 90% 1RM and reported that maximal power output was achieved at 60% 1RM for both men and women, which agrees with Thomas et al. [1] findings regarding the high pull. Cumulatively, the previous and current findings (Figure 1) suggest that resistance trained men and women achieve maximal power output when performing exercises with 30-60% 1RM. However, it appears that resistance trained men produce maximum power at the lower end of the range (30-40% 1RM) when compared to women (50% 1RM) and these relationships may be exercise specific [1,7,8].

An additional novelty of the present investigation suggests that training status directly influences the intensity that maximal power output is produced. The present data reveals that trained individuals produce maximal power output at a lower relative intensity of 1RM for either exercise. The data indicate that trained men and women produce maximal power at 30-40% 1RM and 50% 1RM, respectively, compared to untrained men and women producing maximal power at 60-70% 1RM. Further, maximal 2LP was achieved at 40 and 50% 1RM for trained men and women, while untrained men and women produced maximal 2LP power at 60 and 60-70%, respectively (Figure 1). In agreement to the current results, Baker et al. [4] concluded that resistance trained athletes display maximal power output at a lower relative intensity than untrained individuals, and suggested that the differences in power output may be due to strength differences. However, additional research has observed that maximal power output is achieved at the same relative intensity during the jump squat between trained and untrained individuals despite observing significant strength differences [9–11]. These conflicting results suggest that training status may affect maximal power output based on exercise selection and not absolute strength. Furthermore, unpublished data from our laboratory suggests that vertical jumps can be a reliable measure; however, the variability of jump metrics are influenced by how the jump is performed such that the inclusion of arm movement decreases reliability between jumps. Thus, the increased variability observed from performing squat jumps may have contributed to the non-significant findings between trained and untrained individuals. Previous literature suggests that relative strength may influence maximal power more than absolute strength [18]. The present observations agree with this assertion, which indicate that resistance trained men and women have significantly greater relative strength values for BP ($p<0.001$) and 2LP ($p<0.001$), and produce maximal power at a lower relative intensity.

An explanation regarding the differences in the optimal power output load between trained men and women, as well as trained and untrained individuals, may have been attributed to neuromuscular factors such as morphological or neural factors [19]. Regarding the differences between men and women, it has been noted that men have significantly ($p<0.001$) more muscle mass than women at a relative and absolute measure [15]. Additionally, men tend to possess a greater amount of fast twitch muscle fibers, while women tend to have a predominance of slow twitch fibers [12]. Thus, the greater amount of muscle mass and higher proportion of fast twitch muscle fibers may explain the differences noted between men and women. Furthermore, those who qualified as resistance trained, which had three or more years resistance training experience, may have accrued long term training adaptations [2,19,20]. Similar to men and women, fiber type distribution may have attributed to the differences between trained and untrained individuals. Previous research has reported that resistance trained individuals possess a greater amount of fast twitch fibers when compared to untrained individuals; additionally, those who were endurance trained but did not resistance train may have had a predominance of slow twitch fibers [13,20]. The differences in muscle fiber type may contribute to where optimal power is produced as previous literature has indicated that type II fibers have a greater capacity to generate power per unit of cross-sectional area [19]. Further, a predominance of type II fibers (men versus women) or fibers displaying type II characteristics (resistance trained versus untrained participants) could decrease cross-bridge cycle time, inevitably increasing the ability to develop force rapidly [19].

The findings of this investigation are in agreement with previous literature indicating that maximal power output is achieved between 30-50% 1RM during an upper body exercise (BP or BP throw) in trained men and women [1,5,7,20–23]. Previous research has also examined maximal power output for lower body exercises such as various forms of squats, cleans, jumps, and deadlifts [1,3,5,8,10,11,20,21,24]. The consensus on lower body movements remains unclear with optimal loads ranging from 0-80% 1RM. An explanation for this variability could be due to exercise selection. For example, Cormie et al. [3] evaluated three lower body exercises (jump squat, barbell squat, and power clean) and reported that optimal power was produced at different intensities (0%, 56%, and 80% 1RM, respectively) for each exercise. Furthermore, the authors suggested that power output is influenced by the characteristics of a specific lift. For example, a jump squat is ballistic in nature, while a barbell squat requires a deceleration phase toward the end of a repetition. Thus, an additional explanation for the difference in results can be attributed to exercise selection.

The influence of methodology contributed to the novelty of design as well as potential limitations for this investigation. To our knowledge, the utilization of a machine based exercise (2LP) for quantifying muscular power was novel in design. The choice of 2LP for lower body power output was selected for its relative ease of completion and its high degree of safety for both trained and untrained individuals. Furthermore, our reliability analyses indicated that the power and velocity measures were reliable (ICC= 0.77-0.98) with minimal error (2.8-7.2%) between testing sessions for the 2LP. This is also the first investigation to incorporate multiple barbell BP weights to accurately achieve every load across intensities for both participants. For example, several untrained women had a 1RM BP of 60 pounds (27.2kg); by incorporating a minimum barbell weight of 12 pounds (5.45kg) we were able to accurately assess BP power at 20% 1RM. An additional consideration of the current investigation is the use of the TFDA. Previous investigations have used similar devices, force plate technology, as well as pneumatic technology in the assessment of muscular power. Nonetheless, previous research advocates the use of TFDA in laboratory settings [25–27] with much more convenience than the additional devices. Although the present study provides novel insight regarding maximal power production, it is not without limitations. Most notably, the present design required participants to perform a single repetition at each of the relative intensities during the power testing, which may not have provided reliable power measures. However, each participant was required to become familiar with all testing procedures, and our reliability analyses indicated that the power measures obtained from the TFDA provided moderate to high reliability. Further, the selection of exercise has also been shown to contribute to where maximal power is produced among relative intensities [7,8]. Therefore, the present results should only be applied for the BP and 2LP.

CONCLUSIONS

Strength and conditioning professionals should be aware of individual differences regarding training status. Collectively, these data suggest that resistance trained individuals produce maximal power at a lower relative intensity when compared to individuals with lesser resistance training experience. Further, men appear to produce maximal power at a lower relative intensity when compared to women, and this remains true when evaluating sex based off training status. Cumulatively, when determining where maximal muscular power is produced for the BP and 2LP, it appears that sex and resistance training status must be considered as these data reveal that both factors contribute to maximal power production. From an exercise prescription standpoint, when using the BP and 2LP exercises, novice resistance exercisers may produce more power when employing higher relative loads as compared to resistance trained individuals, which produce maximal power at a lower relative intensity.

Conflict of Interest

The authors declare no conflict of interest.

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