Human Muscle Power Output During Upper- and Lower-Body Exercises

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ABSTRACT

The purpose of this study was to evaluate the use of traditional resistance training equipment in the measurement of muscular power. This was accomplished by measuring the velocity of movement through a measured distance during maximal effort lifts using a Smith rack. The reliability of the method was established using 10 male volunteers who performed both bench press and squat exercises in a Smith rack. Maximal power output was determined at 30, 40, 50, 60, 70, 80, and 90% of the subject's 1 repetition maximum (1RM). Test-retest power values were not statistically different. Another 15 male volunteers who had previous muscle biopsy data from the vastus lateralis muscle performed the same maximal power output evaluation. There were no significant relationships between peak power outputs and fiber-type expressions when linear regressions were performed. The power curve produced by graphing power output vs. the percentage of 1RM indicates that peak power output occurs between 50 and 70% of 1RM for the squat and between 40 and 60% of 1RM for the bench press. These data indicate that this method of evaluation of muscle power is reliable, although it is not predictive of muscle fiber–type percentages.

Key Words: resistance training, performance testing, specificity

Introduction

Power is defined as the rate of doing work (15), or in applied terms, it is the explosiveness produced by the muscles during athletic events. The force-velocity curve of muscle states that during concentric muscle actions, as the velocity of movement increases, the ability of the muscle to produce force decreases. Maximum power, therefore, is achieved at a compromised level of maximal force and velocity. At what combination of strength and speed does one train to enhance power output? Peak power during concentric muscle actions has been shown at intermediate velocities of movement of approximately 30% of maximum shortening velocity (14). Untrained young women achieved maximum power outputs at 56–78% of the 1 repetition maximum (1RM) load during the leg press exercise (23). Maximal mechanical power output of the elbow flexor muscles of male subjects occurred at 30% of maximum isometric strength (14).

Previous research reporting power measurements (1–4, 7–9, 12–14, 16–19, 23, 25, 26) approached the specificity of resistance training question from a scientific, rather than a practical, viewpoint. Muscular components (such as hypertrophy) and neural components (such as synchronization, activation power, coactivation, and orderly recruitment) have been studied. The relationship between power output and muscle fiber–type expressions have also been examined (6, 10, 11, 21, 22, 24), with results supporting both the existence of a relationship (6, 11, 21, 24) and the lack thereof (10, 22).

The specificity of muscle power training is well documented (1–4, 7–9, 12–14, 16–19, 23, 25, 26). In order to measure the benefit of a traditional resistance training program, it would be ideal to incorporate the training equipment into the testing procedure. However, the evaluation of muscular power is usually accomplished by the use of field tests such as the jump-reach or seated shot put tests. Realizing that better methods of evaluation may allow better program design, the purpose of this study was (a) to evaluate the reliability of a method to measure human skeletal muscle power with the use of traditional resistance training equipment, (b) to identify the shape of the power curve (power vs. force), (c) to compare the shape of the power curve between upper- and lower-extremity exercises, and (d) to evaluate any relationship between the percentage of 1RM at which peak power occurred and the muscle fiber–type composition.
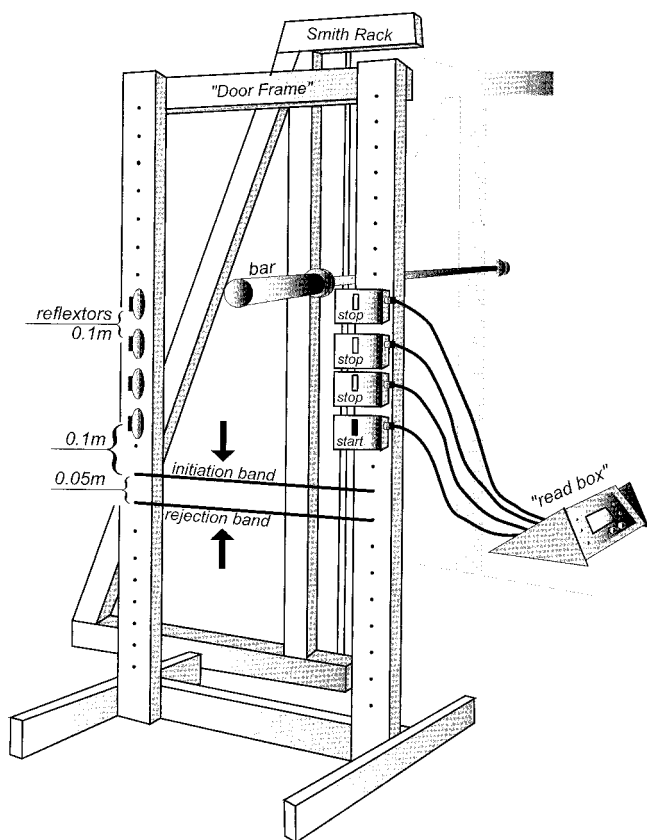
Figure 1.   Power measurement apparatus with the Smith rack.

Methods

Subjects

Twenty-five male, college-aged subjects volunteered for this study. Ten of the subjects (without previous biopsies) performed the test procedure on 2 occasions to establish reliability of the measurement. Fifteen of the subjects who had given muscle biopsies for a previous study (5) 3 months prior to the present study performed the test procedure once. Prior to beginning the study, the protocol was approved by the Ohio University Institutional Review Board and each subject was asked to read and sign an informed consent statement. All subjects had prior resistance training experience and were familiar with the 2 lifts (squat and bench press) used in this study.

Apparatus

A wooden "door frame" apparatus was constructed (Figure 1) to allow the determination of time elapsed during linear movements through the vertical axis of the frame. Holes drilled in the uprights of the door frame allowed the attachment of horizontal chronoscopic timing lights (on 1 upright,) and reflectors (on the other upright) at 0.05-m intervals. With the door frame placed at the end (and perpendicular to) the bar of a Smith rack, the bar would pass through the light beams created by the chronoscopic timing lights (Mod-

el 63501 IR, Lafayette Instrument Company, Lafayette, IN). This apparatus was connected to a timing device (CLOCK Model 54050, Lafayette) and was used to determine time elapsed during the performance of a squat and a bench press exercise.

Prior to data collection, the bottom position of each exercise was determined: for the squat, the tops of the thighs were parallel to the floor; for the bench press, the bar was in contact with the chest. For the squat exercise this position was marked on the apparatus to the nearest 0.05-m mark. An elastic band was placed at this point and designated as the initiation band. A second elastic band was placed 0.05 m below the initiation band; this band was designated as the rejection band. For the bench press exercise the initiation band was placed 0.05 m above the level of the bar on the chest, and bouncing the bar off of the chest was used as a rejection criteria. To determine measurements of elapsed time, a "start" light was placed 0.1 m above the initiation band. During the squat exercise, "stop" lights were placed at 0.1, 0.2, and 0.3 m above the start light. During the bench press exercise, stop lights were placed at 0.1 and 0.2 m above the start light (arm length did not allow the use of a third stop light).

During the performance of a lift, the subject was instructed to lower the bar until the bottom position was attained. The tester provided a verbal command when the bar contacted the initiation band, but the subject was not required to wait until the command was given. However, if the bar did not contact the initiation band or if the bar made contact with the rejection band or was bounced off of the chest (bench press), the lift was not recorded. This procedure provided control over the amount of momentum the subject could generate prior to the beginning of the timing process while ensuring the same start point within the subject's range of motion.

Testing

Prior to any lifting exercises, subjects were permitted to warm up. Testing required 3 days (5 days for subjects performing the reliability evaluation) of data collection. On day 1, each subject's 1RM was determined (20) for the squat and the bench press. The Smith rack was used on the squat exercise to ensure a linear vertical movement pattern of the bar through the timing lights during the power testing. The same procedure was therefore used during the 1RM squat testing. Control of the vertical movement pattern of the bar was not a problem for the bench press exercise, and free weights were used during bench press 1RM and power testing. On day 2 the subject performed maximal velocity lifts at 50, 70, 30, and 90% of their 1RM. On day 3 the subject performed maximal velocity lifts at 60, 40, and 80% of 1RM and 1 other point that corresponded to a 5% increment where the investigator hypothesized a peak in power would occur. This proce-

dure was used to reduce the effects of residual fatigue of previous lifts on subsequent lifts. Days 2 and 3 were separated with a day of rest. The subjects performing the reliability evaluation repeated the procedures of days 2 and 3 on testing days 4 and 5.

Subjects were instructed that the bar must be lowered under control until they reached the bottom position. Upon reaching this position (or hearing the lift command), the subject was instructed to push the bar up as fast and as explosively as possible. The subject was not instructed to perform a jumping action during the squat exercise or to explode off the bench surface during the bench press exercise, but if ground or bench contact was not maintained during the effort the measurement was still valid. There was no mandatory pause or signal that marked the initiation of the explosive lift. The rejection criteria listed previously were used to determine recorded efforts.

After 1 repetition, the subject was required to re-rack the bar and rest for a period of 1–2 minutes. Five repetitions of each percentage were performed before moving onto the next percentage of 1RM. For each repetition performed, time measurements were recorded for the 0.1-m distance, the 0.2-m distance, and the 0.3-m distance (squat only).

The 5 repetitions for each load lifted yielded 5 sets of time values. Of these 5 sets, the fastest 3 were selected and averaged together for use in the power calculations. Power, measured in Watts, was calculated for each load at 0.1-, 0.2-, and 0.3-m (squat only) distances. Power outputs were also calculated for the second 0.1-m and third 0.1-m (squat only) distances. These values were calculated based on times obtained by subtracting 0.1 m from 0.2-m times and by subtracting 0.2 m from 0.3-m (squat only) times.

Fifteen subjects in this study had muscle biopsies performed during participation in a previous study 3 months prior (5). Biopsies were obtained from the vastus lateralis muscle (5), and muscle fibers were classified into 6 fiber types using routine myofibrillar ATPase histochemistry. Hybrid fiber types were condensed into the 3 common types for the purpose of this study using the following formula: type I = type I + type IC, type IIA = type IIA + type IIC + 0.5 type IIAB, and type IIB = type IIB + 0.5 type IIAB. The percent fiber–type area was calculated from the percent of each fiber type and the average fiber area for each type.

Statistical Analyses

The data from the 10 subjects who performed the test procedure on 2 occasions were analyzed for reliability. A 2-way repeated measures analysis of variance (ANOVA) with 2 within subject factors was used to measure differences between trials for the power value produced at each percentage of 1RM. A p value of less than 0.05 was used to indicate a significant difference.

Table 1. Physical characteristics of the 15 biopsy subjects.*

Variable	M	± SD	Range
Age (years)	23	4	18–32
Height (cm)	178	6	168–193
Weight (kg)	79.3	14.1	62–119.2
% Fiber type I	43	9	26–64
% Fiber type IIA	39	10	23–57
% Fiber type IIB	18	9	2–33
% Fiber type I area	39	9	27–65
% Fiber type IIA area	43	11	28–63
% Fiber type IIB area	18	10	0–36
1RM bench (kg)	89	30	57–184
1RM squat (kg)	136	23	107–193

* M = mean; SD = standard deviation; 1RM = 1 repetition maximum.

**Table 2.** Regression coefficients for power measurements and percent fiber area for the squat exercise.*

Point of peak power measurements	Percent fiber area		
	Type I	Type IIA	Type IIB
First 0.1 m	−0.11983	−0.58810	0.18534
First 0.2 m	−0.28284	0.28146	−0.04488
First 0.3 m	−0.04273	0.18138	−0.16616
Second 0.1 m	−0.24609	0.36891	−0.18141
Third 0.1 m	−0.08848	−0.04409	0.13762

* None of the regression coefficients were significant.

The power data from the 15 subjects who had previous biopsy data were analyzed to determine if a significant relationship existed between power production and fiber-type composition. The percentage of 1RM corresponding to the peak in the power curve was determined for each subject at each movement distance 0.1, 0.2, and 0.3 m (squat only); second 0.1 m and third 0.1 m (squat only); and for each lift. A linear regression was used to analyze the relationship between the peak power and the percentage of fiber types I, IIA, and IIB and fiber-type areas. A significant regression equation was indicated by a p value less than 0.05.

Results

The physical characteristics of the 10 subjects who performed the test-retest reliability evaluation were not recorded; the physical characteristics of the remaining 15 subjects with previous muscle biopsy data can be seen in Table 1. Analysis of the test-retest data found no statistical differences between trials for the 5 squat exercise distances or for the 3 bench press distances evaluated. The power outputs obtained during the 2
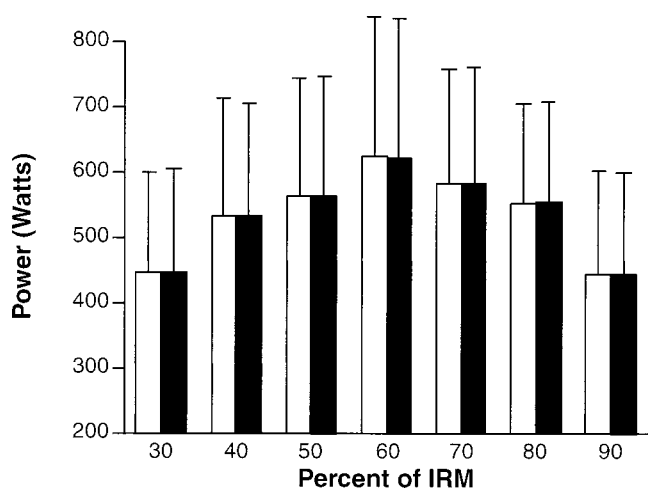
Figure 2. Reliability of power measure for the first 0.1-m distance during the squat exercise (open square = trial 1, filled square = trial 2). There were no significant differences between trials at this distance or at any of the other 4 distances tested. Values are means ± standard deviations.
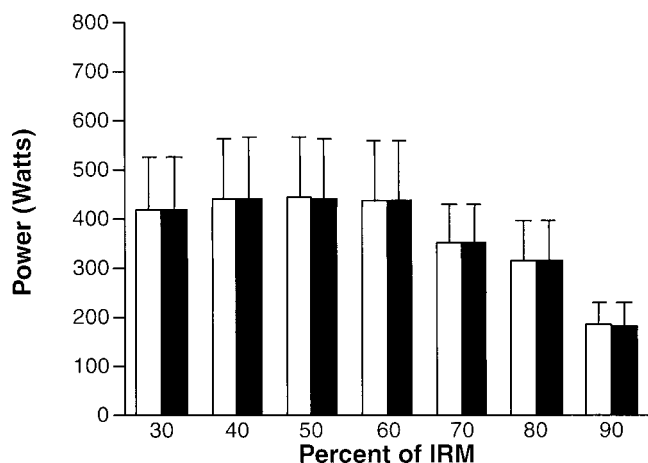
Figure 3. Reliability of power measure for the first 0.1-m distance during the bench press exercise (open square = trial 1, filled square = trial 2). There were no significant differences between trials at this distance or at any of the other 2 distances tested. Values are means ± standard deviations.

trials for the first 0.1-m distance can be seen in Figures 2 (squat) and 3 (bench press.) These data indicate that the procedure was reliable.

Regression analysis of percentage of 1RM at peak power to fiber type or to fiber-type cross-sectional area revealed no significant regression coefficients. Tables 2 and 3 include the regression coefficients for the point of peak power measurements and the percent fiber area for the squat and bench press exercises, respectively. There were no significant regression coefficients.

The data of all 25 subjects were used to produce an average power curve for all measurement distances during both lifts (see Figures 4 and 5). Visual inspec-

Table 3. Regression coefficients for power measurements and percent fiber area for the bench press exercise.*

Point of peak power measurements	Percent fiber area		
	Type I	Type IIA	Type IIB
First 0.1 m	−0.11796	−0.09366	0.22351
First 0.2 m	−0.19896	−0.04794	0.25070
Second 0.1 m	−0.20938	0.03350	0.16747

* None of the regression coefficients were significant.
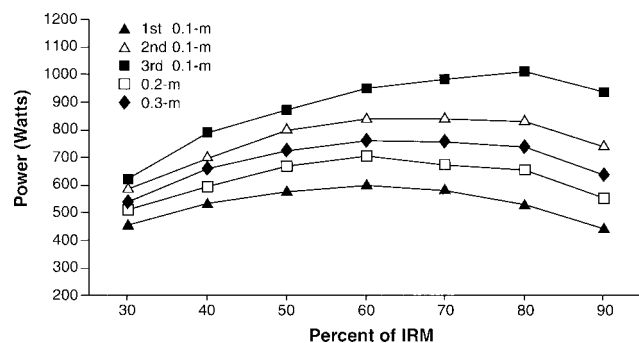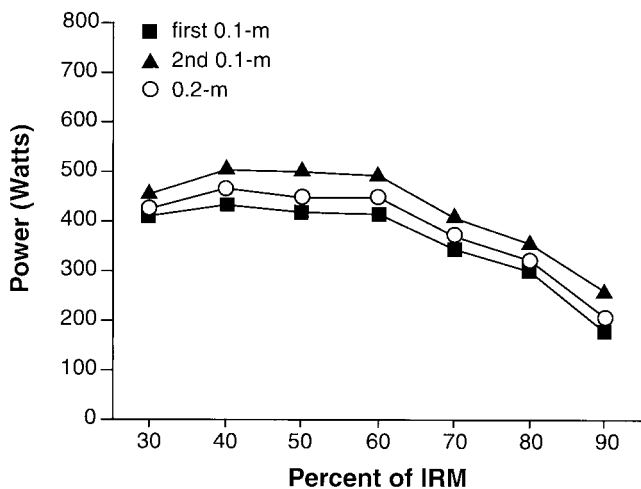

Figure 4. Maximal power output at various percentages of 1RM for the squat exercise. Curves represent power measured at 0.1-, 0.2-, 0.3-, second 0.1-, and third 0.1-m distances.

tion of Figure 4 reveals that 4 of the squat curves peak at 60% of 1RM; the lone exception is the third 0.1-m distance, which peaks at 80% of 1RM. "Plateauing" for the squat curves also occurs from 50 to 70% of 1RM for the first 0.1- and 0.2-m distances; however, the plateau continued to 80% of 1RM for the 0.3-m and the second 0.1-m distance. A peak occurs for the 3 bench press curves at 40% of 1RM. All 3 curves plateau with less than a 5% decline in power at both 50 and 60% of 1RM.

Discussion

Quick, explosive movement is a vital component to athletic performance. The relationship between improvements in power output and enhanced athletic performance is a simple concept. However, the application of this concept to the practical setting is not well established. In this study, a new device, which used chronoscopic timing lights and traditional resistance training exercises to measure power, demonstrated statistical reliability at all 8 measurements evaluated. This indicates that this technique could be used to evaluate the effectiveness of traditional weight-training programs to enhance or alter power curves.

The results of previous research have stated different percentages of 1RM where maximum power outputs occur. Thomas et al. (23) observed maximum power outputs occurring at 56–78% of the 1RM in the

Figure 5. Maximal power output at various percentages of 1RM for the bench press exercise. Curves represent power measured at 0.1-, 0.2-, and second 0.1-m distances.

lower extremity using the leg press machine. Wilson et al. (8) compared 3 training programs to enhance dynamic athletic performance and found that a load of 30% of maximal isometric force during a weighted squat jump was best. The results of the squat exercise from the present study support the data from Thomas et al. (23), with the peak power in the lower extremity occurring at an average of 59.79% of 1RM and with high power outputs continuing from 50 to 80% of 1RM. Differences in results found in the present study and the Wilson et al. (8) study have been explained as the result of the deceleration factor needed in traditional weight-training exercises, as opposed to the lack of deceleration in exercises such as the weighted squat jump. With the deceleration phase at the end of the range of motion in the squat exercise, peak power outputs would become more force-dependent and less velocity-dependent. This would result in peak power occurring at higher 1RM values. This may be indicated in the observation of peak power occurring at 80% of 1RM in the third 0.1-m power curve, near the end of the range of motion of the lift. However, the third 0.1-m power curve is higher than the second and first 0.1-m power curve for all loads, indicating that the bar is still accelerating at this point in the range of motion. If at this point in the range of motion the subject is beginning to slow down, the slowing cannot be detected as a deceleration but it may be present as a decreased acceleration (this cannot be determined from this data). The peak power curve for the first 0.1-m of movement occurs at 60% of 1RM, and one might question if the subject is already decelerating at this point in the range of motion.

The peak and the shape of the squat exercise power curve is related to the distance through which power is measured. This can also be expressed as the amount of time allowed to build momentum before (or during)

the measurement. For example, at 60% of 1RM for the first 0.1-m measurement of the squat exercise the average time elapsed was 0.139 seconds, which yields a mean power output of 600 W. At 60% of 1RM for the third 0.1-m measurement, the average elapsed time is 0.087 seconds, which yields a mean power output of 950 W. However, the average elapsed time for the entire 0.3-m measurement is 0.329 seconds and yields a mean power output of 760 W. Which of these power outputs is the most important? This may be a matter of sport specificity. Various applications differ in the amount of time that is required or allowed to produce peak power output. These data suggest that the recommendations for the enhancement of power output may be dependent on this time factor.

The bench press curves indicate that peak power output was produced at 40% of 1RM, with the plateau ranging from 40 to 60% of 1RM values. These results are similar to the work of Kaneko et al. (14) who suggested that power may be best enhanced by training at 30% of 1RM based on data collected from the elbow flexor muscles. Differences between the upper- and lower-extremity power curves are apparent. In addition to the lower power output measured for the bench press as compared with the squat, the shape of the power curve was also different. Power output was twice as high (0.1-m measurement) at 30% of 1RM (428 W) when compared with 90% of 1RM (214 W) during the bench press. A similar observation is seen at all other measured distances. However, the 0.1-m squat power measurement for 30% of 1RM (454 W) was similar to the 90% of 1RM value (444 W). The remaining 4 measurement distances yielded higher outputs at 90% of 1RM as compared with 30% of 1RM. These differences between the upper and lower extremity may be explained by different muscle groups, ranges of motion, or exercise techniques, but it does appear that power-producing ability is not universal across all muscle and joint systems. These data suggest that the recommendations for the enhancement of power output may depend on the muscle system and body movement being trained.

A relationship between human skeletal muscle fiber–type composition and performance capabilities has often been discussed and studied. Elite distance runners have been characterized to have more slow-twitch fibers, whereas sprinters have more fast-twitch fibers (11). Having a high amount of fast-twitch fibers is suggested to be beneficial for performing activities at high velocities with maximal force, and fast-twitch type IIA fibers have been correlated to higher contraction velocities (6, 21, 24). The opposing argument is also supported in the research; studies exist that have found no correlation between muscle fiber composition and peak power outputs (10, 22). The results produced in this study support this latter finding. No significant regression coefficients were found relating the

percentage of skeletal muscle fiber types or percentage of fiber-type areas to the percentage of 1RM at which peak power occurred. These data suggest that an individual's fiber-type expression is not a predictor of whether an individual will produce peak power at high forces and slow velocities or at low forces and high velocities. This analysis, however, may be limited by the assumption that the small sample size of the biopsy of the vastus lateralis was used to estimate the fiber composition of all of the muscles involved in the squat exercise.

These data indicate that the apparatus used in this study provided a reliable measure of muscle power output. The data indicate that peak power outputs during the lower-extremity squat exercise occurred in the range of 50–70% of 1RM. However, the actual value may depend on the amount of time (distance) allowed to develop peak power. The peak power outputs during the upper-extremity bench press exercise occurred at 40–60% of 1RM and were less dependent on the time to develop peak power. The power output data were not found to be predictive of percentages of muscle fiber types.

Practical Applications

The apparatus used in this study demonstrated reliability in the evaluation of power output. This apparatus may be useful for the evaluation of training programs in research or applied settings. The use of this apparatus to evaluate the shape of power curves (upper vs. lower extremity to compare power outputs at different phases of the range of motion) may also be useful in designing training programs to enhance power output.

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