Effects of Moderate Velocity Strength Training on Peak Muscle Power and Movement Velocity: Do Women Respond Differently than Men?

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Running Head: STRENGTH TRAINING AND MUSCLE POWER SEX DIFFERENCES
ABSTRACT

The effects of a 10-wk unilateral knee extension strength training (ST) program on peak power and velocity at given absolute (force load) and relative (same % of 1 RM) resistances (loads) were examined in 30 older men (64 ± 7 yr) and 32 older women (62 ± 6 yr). As a result of the ST program, peak power (PP) increased significantly in both men and women at the same absolute ($P < 0.001$) and relative loads ($P < 0.01$). Men had a significantly greater increase in relative PP than women with ST at 60% ($P < 0.01$) and 70% ($P < 0.001$) of 1 RM when covarying for baseline differences and age. However, when each subject was tested at the same absolute load and when peak power was normalized for the muscle volume (MV) of the trained knee extensors (i.e., absolute muscle power quality, MPQ), women increased their MPQ by 9% ($P < 0.05$), whereas men did not change. Both men and women increased their absolute peak movement velocity (PV) ($P < 0.001$), but decreased their relative PV significantly with ST ($P < 0.05$). However, when baseline values and age were covaried, women had significantly less of a decrease in relative movement velocity quality with ST than men ($P < 0.01$), but this difference was too small to likely be physiologically meaningful. The absolute muscle power quality data suggest that ST-induced increases in peak power do not rely on muscular hypertrophy in women, but it does in men, providing further support for the hypothesis developed from our previous report (11), that improvements in muscle function with ST result from non-muscle mass adaptations to a greater extent in women than men.

Key Words: Resistance training, movement velocity, sex differences, aging
INTRODUCTION

Sarcopenia is the loss of muscle mass with advanced age and is associated with dysfunction, poor health status, and the loss of muscle strength and power in older adults (17, 18). Muscle power accounts for a greater amount of the variance in physical performance than strength in older adults (3, 9) and deteriorates at a faster rate than strength with advanced age (2, 16, 21). Previous cross sectional data suggests that this decline in peak muscle power with age is associated with muscle structure and function, tendon characteristics, and sarcopenia in specific muscle groups (20).

Previous reports on the effects of strength training (ST) on muscle power did not report how the training affected power per unit of the muscle involvement (muscle power quality, MPQ), or peak velocity (PV) (5, 8, 12, 13, 15), the latter possibly being an important component of power and possibly functional abilities in the elderly. The expression of peak power and movement velocity normalized for muscle volume allows better understanding of potential mechanisms (e.g., hypertrophy and neuromuscular adaptations) for training-induced adaptations. It is also important when comparing groups who possess different amounts of muscle mass, such as men compared to women. For example, in a previous investigation from our lab, we found that muscle quality (one-repetition maximum (1 RM) strength/muscle volume) increased significantly more in women than in men (11). This finding suggests that ST-induced increases in muscle strength in women are preferentially influenced by non-muscle mass adaptations compared to men. Thus, providing support for the hypothesis that other indicators of improved muscle function with ST, such as muscle power and movement velocity may be less dependent on muscle mass increases in women than in men. Moreover, expressing PV changes with ST
relative to the volume of muscle (MV) involved in the movement would better isolate the influences of muscle power changes that are independent of muscle mass.

Furthermore, previous investigations (5, 8, 12, 13) reported peak power as the highest average power obtained during multiple trials of a power test, as opposed to the highest power value attained during a single trial. The highest peak power, i.e., the highest combination of force and velocity that occurs simultaneously during a single trial, might be a more accurate measure of the explosive capacity of the trained musculature than average (area under curve) power of a single trial. This is because average peak power includes two phases of movement that represent reduced power. The first is at the beginning of the movement when one is trying to overcome inertial forces and the other is near the end of the movement when co-contraction of the antagonist muscle group produces a reduced force and velocity. Although some previous investigations did exclude data from the first and last 5% of the range of movement in the power tests (3, 8, 9), these studies still used the average power for a given trial, and reported it as peak power. Thus, there is no information available, to our knowledge, on the effects of ST on peak power. Peak power could conceivably have a different relationship to functional tasks and be affected differently by ST than average power.

In addition, several of the recent training studies that reported changes in leg muscle power with ST did not have an inactive control group to control for biological, methodological, or seasonal variations (3, 5, 8). An untrained contralateral limb is ideal for controlling for drifts in muscle mass or power assessments due to the effects of biological, methodological, or seasonal variation. It also has the advantage over a separate inactive control group by controlling for genetic differences between groups, differences in attention given to the training group
compared to a separate control group, and for differences in physical activity levels between two groups.

Thus, the purpose of this investigation was to determine the effects of moderate-velocity ST on muscle power and movement velocity when normalized for the entire trained musculature involved in the movement (muscle power quality, MPQ, and movement velocity quality respectively) at the same absolute and relative loads in middle-aged and older men and women. It was hypothesized that both absolute and relative peak power of the knee extensors would increase with ST in both men and women, but peak MPQ and peak movement velocity quality, i.e., peak velocity/muscle volume (PV/MV), would be increased to a significantly greater extent in women than in men, based on our previous data (11). We also hypothesized that relative (same % of 1 RM) PV would decrease in both men and women with ST, based on the force-velocity curve, but absolute (same load) PV would increase in both sexes with ST.
METHODS

Subjects. Sixty-two previously inactive, relatively healthy men (n = 30) and women (n = 32) between 50 and 74 years of age volunteered to participate in the study. All subjects underwent a phone-screening interview, received medical clearance from their primary care physician and completed a detailed medical history prior to participating in this study. All subjects were nonsmokers, free of significant cardiovascular, metabolic, or musculoskeletal disorders that would affect their ability to safely perform heavy resistance exercise. Subjects who were already taking medications for at least three weeks prior to the start of the study were permitted into the study as long as they did not change medications or dosages at any time throughout the study. Two subjects were previously diagnosed with type II diabetes mellitus, but were otherwise healthy. After all methods and procedures were explained, subjects read and signed a written consent form, which was approved by the Institutional Review Board of the University of Maryland, College Park. All subjects were continually reminded throughout the study not to alter their regular physical activity levels or dietary habits for the duration of the investigation, and body weight was measured weekly throughout the study to confirm the maintenance of energy balance.

Body composition assessment. Body composition was estimated by dual-energy x-ray absorptiometry (DXA) using the fan-beam technology (model QDR 4500A, Hologic, Waltham, MA). A total body scan was performed at baseline and again after the ST program. A standardized procedure for patient positioning and utilization of the QDR software was used. Total body fat-free mass (FFM), fat mass, and percent fat were analyzed using Hologic version 8.21 software for tissue area assessment. Total body FFM was defined as lean soft tissue mass plus total body bone mineral content (BMC). The coefficients of variation (CV) for all DXA

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measures of body composition were calculated from repeated scans of 10 subjects who were scanned three consecutive times with repositioning. The CV was 0.6% for FFM and 1.0% for % fat. The scanner was calibrated daily against a spine calibration block and step phantom block supplied by the manufacturer. In addition, a whole body phantom was scanned weekly to assess any machine drift over time.

Body weight was determined to the nearest 0.1 kg with subjects dressed in medical scrubs, and height was measured to the nearest 0.1 cm using a stadiometer (Harpenden, Holtain, Wales, UK). Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared.

**Strength testing.** One-repetition maximum (1 RM) strength tests were assessed on the knee extension exercise before and after the ST program using an air-powered resistance machine (Keiser Sports/Health Equip. Co., Inc., Fresno, CA). This exercise was chosen because it could easily be tested in a standardized way using objective criteria. The 1 RM test was defined as the maximal resistance that could be moved through the full range of motion with proper form one time. Approximately the same number of trials (6-8) and the same rest periods between trials (~ 1 min) were used to reach the 1 RM after training as before training. Before the regular ST program, 1 RM testing, and power testing were performed, subjects underwent at least three familiarization sessions in which the participants completed the training program exercises with little or no resistance and were instructed on proper warm-up, stretching and exercise techniques. These low-resistance training sessions were conducted in order to familiarize the subjects with the equipment, to help control for the large 1 RM strength gains that commonly result from skill (motor learning) acquisition during the initial stages of training, and to help prevent injuries and reduce muscle soreness following the strength testing protocol. The
same investigator conducted strength tests for each subject both before and after training using standardized procedures with consistency of seat adjustment, body position, and level of vocal encouragement. When appropriate, straps and/or belts were used to stabilize the subject so that recruitment of outside muscle groups was minimized. The 1 RM was achieved by gradually increasing the resistance from an estimated sub-maximal load after each successful exercise repetition until the maximal load was obtained. A light system was used to indicate a successful attempt when the knee was extended past ~ 165 degrees. Only those trials that turned on the light were considered successful trials.

*Training program.* The training program consists of unilateral (one-legged) training of the knee extensors of the dominant leg, three times per week, for ~ 10 weeks. Training was performed on a Keiser A-300 air powered leg extension machine. It allows ease of changing the resistance without interrupting the cadence of the exercise. The untrained control leg was kept in a relaxed position throughout the training program.

Subjects warmed-up on a bicycle ergometer for approximately two minutes prior to each training session. Following the three familiarization training sessions previously described, the training consisted of five sets of knee extension exercise. The protocol was designed to include a combination of heavy resistance and high volume exercise. The first set was considered warm-up and consisted of five repetitions at 50% of the 1 RM strength value. The second set consisted of five repetitions at the current 5 RM value, which was initially estimated based on our previous data showing that it corresponds to ~ 85% of 1 RM in most people. Adjustments were made as needed during each training session so that the resistance used would result in failure to complete a 6th repetition. The 5 RM value was increased continually throughout the training program to reflect increases in strength levels. The first four or five repetitions of the third set were
performed at the current 5 RM value, then the resistance was lowered just enough to complete one or two more repetitions before reaching muscular fatigue. This process was repeated until a total of 10 repetitions are completed. This same procedure was used in the fourth and fifth sets, but the total number of repetitions was increased in each set to 15 and 20 reps, respectively. This procedure allowed subjects to use near maximal effort on every repetition while maintaining a relatively high training volume. The second, third, fourth, and fifth sets were preceded by rest periods lasting 30, 90, 150, and 180 seconds, respectively. The shortening phase of the exercise was performed in approximately two seconds, and the lengthening phase took approximately three seconds. Subjects perform supervised stretching of the knee extensors and hip flexors following each training session.

Muscle volume assessment. To quantify quadriceps MV, computed tomography (CT) imaging of the trained and untrained thighs was performed (GE Lightspeed Qxi, General Electric, Milwaukee) at baseline and during the last weeks of the 10-week unilateral ST program. Axial sections of both thighs were obtained starting at the most distal point of the ischial tuberosity down to the most proximal part of the patella while subjects were in a supine position. Measurements of MV in the untrained leg served as a control for seasonal, methodological, and biological variation of MV, by comparing the changes in the control leg to the training-induced changes in the trained leg. Section thickness was fixed at 10 mm, with 40 mm separating each section, based on previous work in our laboratory by Tracy et al. (23). Quadriceps MV was estimated based on using a 4 cm interval between the center of each section. Each CT image was obtained at 120 kVp with the scanning time set of 1 s at 40 mA. A 48-cm field of view and a 512 X 512 matrix was used to obtain a pixel resolution of 0.94 mm. Two technicians performed analyses of all images for each subject using Medical Image Processing, Analysis,
and Visualization (MIPAV) software (NIH, Bethesda). Briefly, for each axial section, the cross-sectional area (CSA) of the quadriceps muscle group was manually outlined as a region of interest. The quadriceps CSA was manually outlined in every 10 mm axial image from the first section closest to the superior border of the patella to a point where the quadriceps muscle group is no longer reliably distinguishable from the adductor and hip flexor groups. The same number of sections proximal from the patella was measured for a particular subject before and after training, to ensure within subject measurement replication. Investigators were blinded to subject identification, date of scan, and training status, for both baseline and after training analysis. Repeated measurement coefficient of variation was calculated for each investigator based on repeated measures of selected axial sections of one subject on two separate days. Average intra-investigator CV was 1.7% and 2.3% for investigator one and two respectively. The average inter-investigator CV was < 4.3%. Final MV was calculated using the truncated cone formula as reported by Tracy et al. (23) and described by Ross et al. (19).

Muscle power and movement velocity testing. Determination of peak knee extensor peak power and movement velocity were performed on a customized Keiser pneumatic resistance knee extension (K410) machine (Keiser Sports/Health Equip. Co., Inc., Fresno, CA), specifically designed for muscle power assessment. The K410 machine is equipped with load cell force transducers and position sensors to detect rotary motion at the joint. The K410 hardware is connected to a PC and uses an industrial data collection expansion card to digitize data at 400 times · s⁻¹ from the force sensors and position sensors. This speed is configured and set by the K410 software. Movement velocity assessment is derived from a crystal oscillator on the data collection board.
Prior to testing, seated blood pressure was monitored after five minutes of rest, and then a one minute warm-up was performed on a stationary cycle ergometer. Subjects were then positioned in the K410 with the medial condyle aligned with the axis of rotation of the machine arm. Subjects were instructed to cross their arms across their chest, and a seat belt attached to the machine was then securely fastened around the waist to help isolate the knee extensor muscle group. Subjects were instructed to perform a knee extension with each leg unilaterally at a resistance of ~ 30% of their measured 1 RM and at ~ 50% of their maximal velocity, as a warm-up trial. Following a 30 s rest period, subjects performed three power tests on each leg alternating between right and left at 50%, 60%, and 70% of their 1 RM, with a 30 s rest period between each of the three trials and 2 min rest periods between each increase in resistance. The tester offered standardized oral encouragement to each subject to extend his or her knee as quickly and forcefully as possible during each trial. The highest peak power value of the three trials for each % of 1 RM and the highest (peak) movement velocity attained during this same trial was selected. Although peak movement velocity was selected from the same test trial as peak power, it was measured separately from peak power as the highest velocity obtained during the trial, independent of where peak power was obtained. The entire procedure was repeated 48-72 h later and the peak power values at each resistance level for both baseline tests were averaged in an effort to establish a more stable baseline assessment. This test was repeated during the last week of the 10-week unilateral ST program for the post training test. During this latter test, an attempt was made to find a load that could be replicated from baseline testing that represented 50% or 60% of the post training 1 RM for testing at the same absolute load. When a replicable load could not be found that fell at one of these relative loads (i.e., 50% or 60% of the post training 1 RM), the load that was used at 50% of the baseline 1 RM value was used for the
post training same absolute load (regardless of the % of post training 1 RM that the load represents) during the post training test. The 70% of the post training 1 RM was compared to 70% of 1 RM at baseline for assessing the effects of training on peak power and movement velocity at the same relative load. This relative load was chosen because it is the approximate load where the highest peak power was found at baseline and after training in our pilot data and from other investigations (3, 8). Data for each repetition were passed through a zero-phase forward and reverse digital filter designed using MatLab version 6.0.5 (Math Works Inc., Natick, MA) to remove sensor noise prior to determining the peak power and movement velocity. A low-pass, 10th order Butterworth filter with a cutoff frequency of 10Hz was used. A simple point-to-point search of the power and movement velocity data was conducted to determine the peaks because the resulting power and movement velocity curves are unimodal throughout a single repetition (Figure 2).

Data Analysis. All statistical analyses as described below were performed using SAS software (SAS version 8.1, SAS institute, Inc., Cary NC). To determine if the training programs had an effect on physical characteristics (body mass, body fat, fat-free mass), strength (1 RM), quadriceps muscle volume (MV), peak power, or peak velocity, we conducted a mixed model analysis of covariance (ANCOVA). ANCOVA was used to determine between-group differences (i.e., trained vs. untrained legs) after ST, when baseline values were covaried, to compare changes in MV, peak power, and peak movement velocity. Paired t-tests were used to determine within group changes for each of these variables in the trained and untrained legs. Statistical power calculations revealed values between 0.70 – 0.80, with a significance level set at $P < 0.05$. 
RESULTS

The physical characteristics of the subjects are shown in Table 1. Both men and women increased their 1 RM significantly ($P < 0.001$). However, men had a significantly greater increase in 1 RM than women when covarying for baseline differences and age ($P < 0.05$). There were no other significant changes in any of the physical characteristics shown in Table 1 for men or women with ST. There was a significantly greater increase in the trained leg than the untrained (control) leg for changes in 1 RM ($P < 0.001$), muscle volume ($P < 0.001$), absolute PP ($P < 0.05$), relative PP ($P < 0.01$), relative MPQ ($P < 0.01$), and absolute PV ($P < 0.05$) in men and women. In addition, there was a significantly greater decrease in the trained leg than the untrained leg for relative PV in men ($P < 0.05$), but not in women. There was also a significantly greater increase in the trained leg than the untrained leg for absolute MPQ in women ($P < 0.01$), but not in men. In contrast, there was a significantly greater increase in the trained leg than the untrained leg for absolute movement velocity quality in men ($P < 0.05$) but not in women. Finally, there was a significantly greater decrease in the trained leg than the untrained leg for relative movement velocity quality in men and women (both $P < 0.05$). As expected, within group analyses show that the untrained leg had a significant increase for 1 RM ($P < 0.01$), based on the well established cross-education effect (Table 3). However, there were no other significant changes in the untrained leg (Table 3), indicating that the untrained leg serves as an appropriate control for all other variables.

There was a significant increase in absolute peak velocity (PV) in both men and women ($P < 0.001$). Table 2 shows that there was a significant decrease in relative peak velocity with ST in both men ($P < 0.01$) and women ($P < 0.05$). There were no differences in the changes between men and women for absolute PV or relative PV. Both men and women showed a
significant increase ($P < 0.001$) in muscle volume (MV) with ST, but men had a significantly
greater increase in MV ($P < 0.001$) than women when covarying for baseline values and age
(Table 2). There was a significant increase in absolute MPQ with training in women ($P < 0.05$),
but not in men (Table 2). However, there were no significant differences between men and
women in the changes in absolute MPQ. Both men and women showed a decrease in relative
movement velocity quality ($P < 0.001$) with ST (Table 2). Men had a significantly greater
decrease in relative movement velocity quality than women when covarying for age and baseline
differences ($P < 0.01$), but this difference was too small to likely be physiologically meaningful.

Table 4 shows the baseline and after training values in men and women for both the
trained and untrained legs for 50%, 60%, and 70% of 1 RM. In men, there were significant
increases in relative PP at 50% ($P < 0.001$), 60% ($P < 0.001$), and 70% ($P < 0.05$) of 1 RM in the
trained leg, but not in the untrained leg, whereas in women, there were significant increases in
relative PP at 50% ($P < 0.01$) and at 70% ($P < 0.05$) in the trained leg, and significant decreases
in the untrained leg at 50%, 60%, and 70% of 1 RM ($P < 0.05$). These data confirm that there is
no cross-education effect for PP with ST. With regard to relative PV at 50%, 60%, and 70% of 1
RM at baseline and after ST in men, there were significant decreases in PV with ST in the
untrained leg at 50%, 60%, and 70% of 1 RM ($P < 0.05$). There were significant decreases in
PV at 50% ($P < 0.01$), 60%, and 70% (both $P < 0.001$) with ST in the trained leg. In women,
there was a significant decrease in PV at 70% of 1 RM in the trained leg ($P < 0.01$) and at 60%
and 70% of 1 RM (both $P < 0.05$) in the untrained leg. Between group comparisons indicate that
there was a significantly greater increase in relative PP in the trained leg in men than women at
60% ($P < 0.01$) and 70% of 1 RM ($P < 0.001$) when covarying for baseline differences and age
(Table 4).
Figure 1 shows that there were also significant increases in the trained leg with ST in absolute PP from baseline in both men and women (both $P < 0.001$) when subjects were tested at the same absolute resistance (load). This load represented $61 \pm 2\%$ of 1 RM at baseline and $50 \pm 2\%$ of the improved 1 RM after ST in men, and $63 \pm 2\%$ of 1 RM at baseline and $52 \pm 2\%$ of the improved 1 RM after ST in women. There was no significant difference in absolute PP increases between men and women when covarying for baseline differences and age (Figure 1).
DISCUSSION

The results of the present study demonstrate for the first time, and in support of our hypothesis, that moderate velocity ST significantly increases knee extensor peak power in women, but not in men, when tested at the same absolute load and when normalized for the entire volume of trained musculature (i.e., absolute muscle power quality). When the data are normalized under these same conditions, and tested at the same relative (% of 1 RM) load, both men and women reduce their movement velocity significantly with training (as expected, due to the force velocity relationship), but men show significantly greater reductions than women. However, the magnitude of difference is too small to likely be physiologically meaningful.

Nevertheless, the ST program did increase absolute and relative peak power in both men and women, when not normalized for muscle volume. In addition, both men and women significantly increased their absolute peak movement velocity, but significantly reduced their relative peak movement velocity with training, when not normalized for muscle volume. The ST program did not significantly change relative MPQ in men or women.

The finding of a 9% training-induced increase in muscle power quality in women, but no change in men, supports the hypothesis generated from a previous report from our lab (11) that women may not rely on muscle hypertrophy as much as men to improve muscle function with training. In that report, we suggested that one explanation for the greater increase in ST-induced muscle quality in women than men, could be the preferential influence on non-muscle mass adaptations to ST in women. However, we were unable to find any investigations that addressed the specific mechanisms responsible for this finding with muscle quality or with the finding in our current study with MPQ. Because there was no difference between the changes in absolute peak power, but there were differences in the changes in muscle volume between men and
women with ST, it suggests a training adaptation in women that is less dependent on muscle hypertrophy. It has been reported previously that approximately 40% of the increase in muscular power with ST is due to muscular hypertrophy, and other factors determine the remaining 60% (7). One of these factors is possibly some type of neuromuscular adaptation that compensates for the reduced capacity of women to undergo muscle hypertrophy with ST, compared to men, resulting in a compensatory increase in power per unit of muscle. Support for this hypothesis comes from previous data showing increases in power and strength with ST in older adults can be strongly influenced by neural adaptations (10). This may be due to a greater reduction in the coactivation of the antagonist muscle groups, which has been reported to occur to a greater extent in women than men during the first two months of ST (10). However, there is no data from the present study to support any specific mechanisms for sex differences in MPQ. Further data in support of sex differences in the contribution of muscle hypertrophy to changes in muscle function with ST comes from a recent investigation by Bamman et al. (1) who compared ST-induced changes in strength and myofiber hypertrophy between men and women at different stages of training. They observed similar rates of strength increases for men and women during the first few weeks of training followed by no further increase in strength upon subsequent training in women, whereas, men showed a continuous increase in strength along with greater myofiber hypertrophy throughout 26 weeks of training (1). There is no time course data in the present study from which to speculate any particular mechanisms for explaining our finding of a 9% increase in absolute MPQ in women and no changes in men.

Our finding that both men and women significantly increased their absolute peak movement velocity with ST when using relatively low loads (~ 50% of 1 RM after training) may have important implications for functional abilities. This conclusion is based on recent data
suggesting that selected functional ability performance in older adults may be more dependent on movement velocity at lower external loads than high loads (4). Previous investigations examined the effect of different training velocities on peak power (3, 8), but did not assess the contribution of velocity to enhanced power, which may have more important implications for functional abilities.

The use of the untrained leg also adds a unique contribution to the existing literature on this topic. Our data show that like muscle volume, but unlike strength, there is no cross-education effect on absolute, relative peak power, MPQ, movement velocity, or movement velocity quality. This data confirms its value as a control for normal drift in values due to variations in methodology, biology, season of the year, genetic differences between groups, or differences in attention between experimental and control groups.

Nevertheless, there are limitations with regard to the current investigation. Subjects in this investigation were trained using a moderate velocity training protocol (~ 2 seconds during the shortening phase and ~ 3 seconds during the lengthening phase). Although it could be argued that a higher velocity training protocol is likely to produce greater gains in power (8), we chose to investigate a protocol more commonly used, with an extensive track record for being safe and effective for producing improvements in all the major components of sarcopenia (i.e., muscle mass, strength, muscle quality, and power) (11, 14, 22). It is still not well established whether a high velocity training program is well tolerated by older subjects (6). Finally, the subjects in this study were relatively homogenous with respect to age, but not with respect to race. By self-report, there were 21 African Americans and one Asian American in this cohort, with remainder of subjects being Caucasian. However, race was not a significant covariate in our analyses. Finally, the age range was quite large (50 to 74 yrs), and it is conceivable that the
youngest subjects in the study may have slightly different training responses than the older ones, but age was included as a covariate in our analyses.

Future research needs to be done to examine how this novel method of measuring peak muscle power and normalizing it by the volume of the trained musculature compares to the more common measure of non-normalized average peak power. In addition, this technique needs to be applied to measure the peak power in other movements, such as upper leg extension used in the leg press exercise, as previously reported with average peak power (5, 8). Finally, investigations need to be done to determine the influence of genotypes and racial differences on peak muscle power changes with ST.

ACKNOWLEDGEMENT

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REFERENCES


Table 1. *Physical characteristics at baseline and after strength training (ST) in men and women.*

<table>
<thead>
<tr>
<th></th>
<th>Men (N = 30)</th>
<th>Women (N = 32)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>After ST</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>64 ± 7</td>
<td>--</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.4 ± 6</td>
<td>--</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>82.1 ± 9.2</td>
<td>82.3 ± 9.6</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>27.0 ± 2.9</td>
<td>27.2 ± 3.0</td>
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<tr>
<td>Body Fat (%)</td>
<td>27.1 ± 5.1</td>
<td>26.7 ± 4.8</td>
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<tr>
<td>Fat-Free Mass (kg)</td>
<td>59.7 ± 6.0</td>
<td>60.1 ± 5.6</td>
</tr>
<tr>
<td>1-RM (N)</td>
<td>274 ± 77</td>
<td>353 ± 91*†</td>
</tr>
</tbody>
</table>

Values are means ± SD.

BMI = body mass index; 1-RM = knee extension one-repetition maximum; N = newtons.

*Significantly different than baseline (*P* < 0.001).

†Significantly greater change than women when covarying for baseline differences and age (*P* < 0.05).
Table 2. *Knee extensor peak movement velocity, muscle volume, and muscle quality at baseline and after strength training (ST) in men and women.*

<table>
<thead>
<tr>
<th></th>
<th>Men (N = 30)</th>
<th></th>
<th>Women (N = 32)</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>After ST</td>
<td>Baseline</td>
<td>After ST</td>
</tr>
<tr>
<td>Absolute Peak Movement Velocity^{2} (rad/s)</td>
<td>5.5 ± 0.2</td>
<td>5.9 ± 0.1 ***</td>
<td>4.7 ± 0.2</td>
<td>5.3 ± 0.2 ***</td>
</tr>
<tr>
<td>Relative Peak Movement Velocity^{1} (rad/s)</td>
<td>4.6 ± 0.1</td>
<td>4.0 ± 0.1 **</td>
<td>4.2 ± 0.1</td>
<td>3.9 ± 0.1 *</td>
</tr>
<tr>
<td>Muscle Volume^{3} (cm^{3})</td>
<td>1,713 ± 44</td>
<td>1,878 ± 52 ***‡</td>
<td>1,126 ± 43</td>
<td>1,219 ± 44 ***</td>
</tr>
<tr>
<td>Muscle Quality^{4} (N/cm^{3}) * 10^{-1}</td>
<td>1.6 ± 0.1</td>
<td>1.9 ± 0.1 ***</td>
<td>1.2 ± 0.1</td>
<td>1.5 ± 0.1 ***</td>
</tr>
<tr>
<td>Absolute Muscle Power Quality^{2} (W/cm^{3}) * 10^{-1}</td>
<td>2.5 ± 0.1</td>
<td>2.5 ± 0.1</td>
<td>2.2 ± 0.1</td>
<td>2.4 ± 0.1 *</td>
</tr>
<tr>
<td>Relative Muscle Power Quality (W/cm^{3}) * 10^{-1}</td>
<td>2.4 ± 0.1</td>
<td>2.4 ± 0.1</td>
<td>2.1 ± 0.1</td>
<td>2.1 ± 0.1</td>
</tr>
<tr>
<td>Absolute Movement Velocity Quality^{2} (rad/s/cm^{3}) * 10^{-3}</td>
<td>3.3 ± 0.1</td>
<td>3.2 ± 0.1</td>
<td>4.4 ± 0.2</td>
<td>4.5 ± 0.2</td>
</tr>
<tr>
<td>Relative Movement Velocity Quality (rad/s/cm^{3}) * 10^{-3}</td>
<td>2.7 ± 0.1</td>
<td>2.2 ± 0.1 *** †</td>
<td>3.9 ± 0.1</td>
<td>3.3 ± 0.1 ***</td>
</tr>
</tbody>
</table>

Values are means ± SE; W = watts; rad/s = radians · sec^{-1}; N = newtons.

^{1}70% of 1-RM at baseline and 70% of the improved 1-RM after ST.

^{2}The same absolute resistance at both baseline and after ST.

^{3}Muscle volume of the knee extensors.

^{4}1-RM/Muscle Volume.

*Significantly different than baseline ($P < 0.05$).

**Significantly different than baseline ($P < 0.01$).

***Significantly different than baseline ($P < 0.001$).

†Significantly greater change when compared the other sex when covarying for baseline differences and age ($P < 0.01$).

‡Significantly greater change when compared the other sex when covarying for baseline differences and age ($P < 0.001$).
Table 3. *Untrained (control) knee extensor 1 RM, peak movement velocity, muscle volume, muscle quality, peak power, and movement velocity quality at baseline and after strength training (ST) in men and women.*

<table>
<thead>
<tr>
<th></th>
<th>Men ($N = 30$)</th>
<th></th>
<th>Women ($N = 32$)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>After ST</td>
<td>Baseline</td>
<td>After ST</td>
</tr>
<tr>
<td>1 RM (N)</td>
<td>262 ± 13</td>
<td>289 ± 16*</td>
<td>177 ± 10</td>
<td>186 ± 10*</td>
</tr>
<tr>
<td>Absolute Peak Power$^1$ (W)</td>
<td>405 ± 21</td>
<td>417 ± 23</td>
<td>225 ± 17</td>
<td>212 ± 17</td>
</tr>
<tr>
<td>Absolute Peak Movement Velocity$^1$ (rad/s)</td>
<td>5.6 ± 0.2</td>
<td>5.8 ± 0.2</td>
<td>4.9 ± 0.2</td>
<td>4.9 ± 0.2</td>
</tr>
<tr>
<td>Relative Peak Movement Velocity$^2$ (rad/s)</td>
<td>4.7 ± 0.2</td>
<td>4.5 ± 0.1</td>
<td>4.1 ± 0.1</td>
<td>4.1 ± 0.1</td>
</tr>
<tr>
<td>Muscle Volume$^3$ (cm$^3$)</td>
<td>1,692 ± 50</td>
<td>1,697 ± 51</td>
<td>1073 ± 39</td>
<td>1079 ± 38</td>
</tr>
<tr>
<td>Muscle Quality$^4$ (N/cm$^3$) x 10$^{-1}$</td>
<td>1.6 ± 0.1</td>
<td>1.7 ± 0.1</td>
<td>1.2 ± 0.1</td>
<td>1.5 ± 0.1</td>
</tr>
<tr>
<td>Absolute Muscle Power Quality$^1$ (W/cm$^3$) x 10$^{-1}$</td>
<td>2.5 ± 0.1</td>
<td>2.5 ± 0.1</td>
<td>2.1 ± 0.1</td>
<td>2.1 ± 0.1</td>
</tr>
<tr>
<td>Relative Muscle Power Quality$^2$ (W/cm$^3$) x 10$^{-1}$</td>
<td>2.4 ± 0.1</td>
<td>2.5 ± 0.1</td>
<td>2.0 ± 0.1</td>
<td>2.0 ± 0.1</td>
</tr>
<tr>
<td>Absolute Movement Velocity Quality$^1$ (rad/s/cm$^3$) x 10$^{-3}$</td>
<td>3.5 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>4.7 ± 0.2</td>
<td>4.8 ± 0.2</td>
</tr>
<tr>
<td>Relative Movement Velocity Quality$^1$ (rad/s/cm$^3$) x 10$^{-3}$</td>
<td>2.8 ± 0.1</td>
<td>2.7 ± 0.1</td>
<td>4.4 ± 0.3</td>
<td>4.8 ± 0.3</td>
</tr>
</tbody>
</table>

Values are means ± SE; RM = repetition maximum; W = watts; rad/s = radians · sec$^{-1}$; N = newtons.

$^1$The same absolute resistance at both baseline and after ST.

$^2$70% of 1-RM at baseline and 70% of the improved 1-RM after ST.

$^3$Muscle volume of the knee extensors.

$^4$1-RM/Muscle Volume

*Significantly greater than baseline ($P < 0.01$).
Table 4. *Relative peak power and peak movement velocity at 50%, 60%, and 70% of 1 RM at baseline and after strength training (ST) in men and women.*

<table>
<thead>
<tr>
<th></th>
<th>Peak Power (W)</th>
<th>Peak Velocity (rad/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>After ST</td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trained Leg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% 1RM</td>
<td>453 ± 23</td>
<td>493 ± 25***</td>
</tr>
<tr>
<td>60% 1RM</td>
<td>452 ± 24</td>
<td>488 ± 24***†</td>
</tr>
<tr>
<td>70% 1RM</td>
<td>430 ± 22</td>
<td>456 ± 18***‡</td>
</tr>
<tr>
<td>Untrained Leg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% 1RM</td>
<td>432 ± 22</td>
<td>434 ± 23</td>
</tr>
<tr>
<td>60% 1RM</td>
<td>438 ± 23</td>
<td>442 ± 23</td>
</tr>
<tr>
<td>70% 1RM</td>
<td>413 ± 21</td>
<td>416 ± 21</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trained Leg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% 1RM</td>
<td>262 ± 21</td>
<td>281 ± 20**</td>
</tr>
<tr>
<td>60% 1RM</td>
<td>259 ± 22</td>
<td>271 ± 19</td>
</tr>
<tr>
<td>70% 1RM</td>
<td>244 ± 15</td>
<td>256 ± 13*</td>
</tr>
<tr>
<td>Untrained Leg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% 1RM</td>
<td>262 ± 23</td>
<td>247 ± 22*</td>
</tr>
<tr>
<td>60% 1RM</td>
<td>261 ± 23</td>
<td>245 ± 23*</td>
</tr>
<tr>
<td>70% 1RM</td>
<td>240 ± 18</td>
<td>228 ± 18*</td>
</tr>
</tbody>
</table>

Values are means ± SE; W = watts; rad/s = radians · sec⁻¹.

*Significantly different than baseline ($P < 0.05$).

**Significantly different than baseline ($P < 0.01$).

***Significantly different than baseline ($P < 0.001$).

†Significantly greater change than women when covarying for baseline differences and age ($P < 0.01$).

‡Significantly greater change than women when covarying for baseline differences and age ($P < 0.001$).
FIGURE LEGENDS:

Figure 1. Knee extensor absolute peak power (PP) assessed at the same absolute resistance at both baseline and after strength training (ST) in men and women. There was a significant increase in absolute PP after ST in both men and women (* \( P < 0.001 \)), but there were no significant differences between men and women with regard to changes in absolute PP.

Figure 2. Raw and filtered power (A) and movement velocity (B) curves for one repetition of a knee extensor trial. The raw power and movement velocity were passed through a zero-phase forward and reverse digital filter to remove sensor noise prior to determining the peak power and peak movement velocity. A low-pass, 10th order Butterworth filter with a cutoff frequency of 10Hz was used. A simple point-to-point search of the power and movement velocity data was conducted to determine the peaks because the resulting power and movement velocity curves are unimodal throughout the repetition.
Fig 1.

Absolute Peak Power at Baseline and After ST in Men and Women
Fig 2.

Raw and Filtered Peak Power and Peak Movement Velocity Curves

A.

B.