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Strength and Power Relationships as a Function of Age

MICHAEL G. BEMBEN AND GREGORY A. McCALIP

Neuromuscular Research Laboratory, Department of Health and Sport Sciences, Room 120, Huston Huffman Center, University of Oklahoma, Norman, Oklahoma 73019.

ABSTRACT

The aging process is characterized by a reduction of the physical capacities of coordination, flexibility, strength, and power. Strength generally remains relatively high until 50 years of age when decreases of about 10% per year begin to result in a loss of function and independence; however, little is known about whether neuromuscular power declines in a similar manner or at the same rate as strength. The purpose of this study was to document the muscular strength and power of the upper and lower body and the relationships between the neuromuscular parameters of strength and power for 3 groups of men representing the 20–65-year age range. Healthy, sedentary subjects were recruited into 3 age groups, 20–25 years ($n = 10$), 35–40 years ($n = 8$), and 50–65 years ($n = 7$). Following informed consent and medical clearance, measures of maximal strength (one repetition maximum) and power (piezoresistive accelerometry) were obtained for the upper (bench press) and lower body (leg press), and fat-free body mass was assessed by underwater weighing on 2 separate days. Within-day trial-to-trial reliability was assessed with intraclass correlation coefficients, whereas day-to-day reliability was assessed with Pearson correlation coefficients and dependent *t*-tests. Group differences were explored with analysis of variance and Tukey's post hoc test, and statistical significance was set a priori at a probability level of $p = 0.05$. Day-to-day reliability for each neuromuscular and body composition parameter was excellent for each age group. The oldest men had significantly more body fat ($p < 0.01$) but similar amounts of fat-free tissue when compared with the other groups, yet all measures of strength and power were significantly lower ($p < 0.01$) than the 2 younger groups. Additionally, even though strength and power are theoretically related, the statistical relationships between these 2 parameters were weakest for the oldest group of men and remained fairly independent of each other regardless of the age group being examined. In conclusion, it appears that the ages of 50–65 years represents a critical period when factors other than the amount of fat-free tissue are responsible for the beginning decline in neuromuscular strength and power.

Key Words: aging force production, gerontology, physical capability

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Introduction

Between now and the end of the century, we can expect a 45% increase in the proportion of the population 85 years and older (41). The aging process is typically characterized by a reduction of the physical capacities of coordination, flexibility, strength, power, and velocity (22). Muscular strength remains relatively high until about 50 years of age; after age 60 years, there are dramatic decreases that can lead to loss of function and independence (18, 19, 25, 33).

Muscular strength is the maximal force (expressed in Newtons or kilograms) that can be generated at a given velocity or the maximal load that can be lifted by a specific muscle or muscle group in one maximal effort. Strength is the result of the potential summation and activation of the total cross-sectional area available to the individual from the particular muscle group being used (30). On the other hand, power refers to the ability of the neuromuscular system to produce the greatest possible force as fast as possible. Dynamic power implies that force is exerted through a given distance while the time taken to move the load is recorded, therefore being a function of both strength and speed of movement. Additionally, power essentially combines 2 strength factors: force and velocity. The larger the force and the more quickly that force is generated, the larger the power output (17); generally, the greatest gains in power will occur only when strength and speed both increase (21). Since maximum strength is needed to achieve maximum power, one might assume that a direct relationship exists between the neuromuscular measures of strength and power (36). If strength and power are somewhat dependent on each other and have both been implicated in the maintenance of balance and for the reduction in the risk of falling in the elderly, then it would seem important to examine these 2 parameters and their relationship to one another for different age groups and muscle groups. In this manner, a better understanding of basic neuromuscular function can be determined for different age groups, and perhaps better exercise programs could be designed for specific outcomes relevant to different age-related needs.

In most published reports, power is generally referred to as a measure of metabolic function, i.e., anaerobic power, as determined by tests such as the Wingate bicycle test. Other tests found in the literature that report the measurement of power include arm cranking (15), vertical jumping (13), treadmill running (32), the acceleration of a weighted fly wheel (3), and isometric rates of force production (20). However, an important issue relative to functional ability during aging is the consideration of neuromuscular power, not in terms of metabolic consequences, but rather in terms of one-time explosiveness. In this manner, additional information may be obtained regarding the influence of age on basic neuromuscular parameters, since power has been implicated to be more directly related to losses of physical function than changes in strength with increased age (2, 3).

Therefore, the purposes of this study were to develop a method that could be used to assess another parameter of neuromuscular function, namely, power, and then determine the relationships between muscular strength and muscular power of the upper and lower body for 3 different groups of men representing the 20–65-year age range.

Methods

Sample and Protocol

The subjects chosen represented 3 different age groups: 20–25 years of age ($n = 10$), 35–40 years of age ($n = 8$), and 50–65 years of age ($n = 7$). Power analyses (9) indicated that even with the small sample sizes, effect sizes were quite large so that β or statistical power, the ability to detect statistical differences, was acceptable (0.80) for most comparisons.

Each volunteer was healthy, i.e., free from overt cardiovascular problems such as high blood pressure and free from any orthopaedic limitations at the time of testing. Additionally, each volunteer must have been able to lift at least 45.5 kg for a bench press test on the Cybex Smith linear press machine and must not have participated in organized athletics within the past 2 years (moderate leisure-time activities, i.e., golf, tennis, etc., were permissible) or weight trained during the last 12 months. These strict limitations in activity levels were used to help remove the possible advantage that physically active individuals might have in regard to the ability to produce power through better neuromuscular coordination and familiarization with different movements, i.e., weight lifting.

A medical clearance form from each subject's personal physician, for subjects 40 years and older, was required, and subjects were required to give their written informed consent to participate in the study. Approval for the use of human subjects was obtained from the Institutional Human Subject Review Board at the University of Oklahoma. For each subject, data were collected on 2 separate days to establish the reliability for each different age group regarding strength and power measures, and each test session lasted approximately 60 minutes.

Instrumentation and Measures

Strength. Subjects were required to perform a one-repetition-maximum (1RM) bench press and leg press test to determine upper- and lower-body strength, respectively. For this testing, a Cybex Smith linear press machine and an Icarion 45° leg press were used, since these 2 machines minimize the effects of balance, technique, and momentum that novices might experience. The Icarion 45° leg press machine required the subject to be in a semireclined position so that the pressing motion occurred in an upward 45° angle away from the floor.

Each subject was instructed on the proper testing procedures for both the Smith press and the Icarion leg press before beginning the exercise. The grip placement requirement when performing the 1RM bench press was continually monitored. The index finger of each hand had to touch the outer ring of the bar during the entire lift. The subjects were instructed to lower the bar while maintaining control and without bouncing the bar off of their chest. Feet were placed flat on the floor, and the gluteus maximus remained touching the bench at all times. The back could have been arched during this exercise as long as the gluteus maximus stayed on the bench. This protocol was first described by Elliot et al. (12), and these criteria were considered imperative to ensure a successful lift. Each subject did a 10-repetition warm-up at 50% of their body weight on the bench press. After a 2-minute rest, each subject then began the 1RM protocol, beginning with 60% of their body weight. The 1RM for the upper body was achieved by the fifth trial, with a 2-minute rest between trials. To ensure consistency in their efforts, no encouragement was allowed. This procedure has been found to reduce the variability of the instructions given by the testers, to improve the reliability of bench press maximal lifts (8), and to be a valid test of strength (4).

Lower-body strength required each subject to be in a semireclined position in the Icarion seated leg press machine. Each subject was instructed on proper leg press techniques before testing. The 1RM measurement for the leg press was achieved within 5 attempts after a brief warm-up. Each subject warmed-up with his body weight 10 times; then after a 2-minute rest, they began the process of reaching maximum strength using the 1RM procedure mentioned herein. These standardized protocols for assessing strength were developed by Stone and O'Bryant (39).

Power. To determine muscular power, a uniaxial piezoresistive accelerometer (ICSensors, model 3145) was attached to the weight equipment. Whenever the accelerometer was displaced or moved, the movement caused a change in the electrical resistance of the accelerometer, which then registered as a change in the acceleration signal. With the aid of an A-to-D board, these electrical signals were converted to digital signals and stored in a computer. In general, by moving the mass and recording the speed of the movement, average power (AP) can be calculated for any portion of the lift or peak power (PP) can be determined for the entire lift.

For assessing upper-body power, each subject initially warmed up with 50% of his body weight for 10 repetitions before testing. After 2 minutes of rest, the Smith Press was loaded with 60% of the individual's 1RM. The starting position required the bar to be placed on the subject's chest. Each subject then performed 3 trials, lifting the bar as fast as possible, with a 1-minute rest between each trial.

Measurement of lower-body power was assessed using a method similar to that of assessing lower-body strength. The accelerometer was placed on a wood block set perpendicular to the floor to account for the 45° angle of the leg press itself. In this way, only movement in the vertical direction was assessed, and power then was calculated as the power required to lift the weight vertically. Each subject performed 10 repetitions with their body weight as a warm-up exercise; then after a 2-minute rest period, the subject performed 3 power trials with a load equal to 60% of their leg press 1RM. There was a 1-minute rest between each trial. Subjects were instructed to lower the weight until given the ''press'' signal, then were required to push the weight up as fast as possible until their legs were fully extended.

The accelerometer data were imported into Quattro Pro for Windows. The starting point of the lift was determined where the acceleration signal first increased from its baseline reading. The acceleration data were then averaged on a point-by-point basis, which allowed for the calculation of average acceleration for every 1/60th of a second. The average acceleration value was then multiplied by the time interval between the data points (0.0167 seconds) as a numeric integration of the acceleration signal to yield the instantaneous velocity at each data point:

$$\text{Instantaneous Velocity} = \text{Average Acceleration} * 0.0167 \text{ seconds}$$

The velocities were summed consecutively to measure absolute velocity throughout the lift, and it was determined that the lift was completed at the first point that the summed velocity dropped below zero:

$$\text{Velocity}_{\text{accelerometer}} = \sigma \text{ Instantaneous Velocity, while } \sigma \geq O$$

The summed velocities were then multiplied by the measurement of force to obtain power measures at all data points during the lift. Force was calculated by the multiplication of the weight lifted (in kilograms) and the sum of the acceleration due to gravity and the acceleration of the bar, according to the accelerometer signal at each specific data point:

$$\text{Force}_{\text{acceleration}} = (\text{Acceleration} + [9.8 \text{ m/s}^2]) * \text{mass}$$

In this manner, the acceleration of the bar to be measured dynamically, rather than using a static measurement of acceleration, needed to overcome gravity. Power was measured by multiplying force and velocity on a point-by-point basis, thereby giving an accumulating measure of power.

$$\text{Power}_{\text{acc}} = \text{Force}_{\text{acc}} * \text{Velocity}_{\text{acc}}$$

Parameters related to the concept of neuromuscular power included AP, the power over the entire lift, PP, the highest instantaneous power occurring during a lift, time to peak power, total time, and power during the first third (1/3P), middle third (2/3P), and last third (3/3P) of a lift.

Body Composition and Anthropometric Measures. Body composition (fat and fat-free mass) was assessed by underwater weighing. Body composition refers to the percentage of body weight that is fat, and its measurement is based on the assumption that body weight can be dichotomized into fat weight and fat-free weight (1). The criterion measure for assessing body composition using the 2-component model is hydrostatic (underwater) weighing (7). Body weight was measured using a calibrated AccuWeigh 3-beam balance scale. Residual lung volume was estimated from vital capacity measures taken on a Vitalograph model spirometer (VC X 0.24). Although direct measurement of residual lung volumes are preferred, an error of only 0.003 $gm \cdot cc^{-1}$ has been documented with this technique (37). The subjects' underwater weight was assessed using a Transducer Techniques model TI-3000–3.5 amplifier attached to a 22.7-kg load cell interface. From the measured body densities, body fat percentages were calculated using the Siri equation: $\%Fat = [(4.95/\text{body density}) - 4.5] \times 100$ (38).

Estimated muscle-plus-bone cross-sectional areas were also calculated for both the upper arm and thigh, using thigh and arm circumferences and correcting for subcutaneous fat from the respective limbs. Limb circumferences were measured to the nearest millimeter using an Evans/Rule steel tape. The thigh measures were taken at the midpoint between the hip and the knee (the midline of the anterior aspect of the thigh, midway between the inguinal crease and the proximal border of the patella) and at the shoulder and elbow midpoint (midline of the posterior aspect of the arm, at a point midway between the lateral projection of the acromion process of the scapula and the inferior mar-

Table 1. Subject characteristics (mean ± *SEM*) by age range.

Variables	20–25 y	35–40 y	50–65 y
Age (y)	22.9 ± 0.4	36.6 ± 0.6	61.2 ± 2.8
Height (cm)	177.4 ± 2.9	174.2 ± 2.3	175.1 ± 3.1
Body weight (kg)	81.9 ± 4.8	84.2 ± 6.8	85.3 ± 4.8
Body density ($g \cdot cc^{-1}$)*	1.050 ± .005 ***a***	1.034 ± .005 ***ab***	1.026 ± .004 ***b***
%Fat*	21.4 ± 2.1 ***a***	28.0 ± 2.2 ***ab***	32.5 ± 1.7 ***b***
Fat-free weight (kg)	63.8 ± 2.8	59.9 ± 3.8	57.3 ± 2.1
Chest circumference (cm)	97.4 ± 2.7	101.0 ± 3.7	101.6 ± 1.7
Shoulder–elbow (cm)	32.0 ± .5	33.1 ± .4	33.9 ± .8
Elbow–wrist (cm)	27.8 ± .6	27.3 ± .7	27.7 ± .7
Total arm (cm)	59.7 ± 1.0	60.3 ± .8	61.6 ± 1.2
Hip–knee (cm)	43.7 ± 1.0	43.3 ± 1.2	43.3 ± 2.7
Knee–ankle (cm)	38.5 ± 1.4	36.2 ± .8	37.0 ± 1.4
Total leg (cm)	82.3 ± 1.0	79.5 ± 1.6	81.3 ± 3.4
XSA upper arm (cm^2)†	69.8 ± 4.1	70.6 ± 6.3	63.5 ± 2.3
XSA thigh (cm^2)	208.8 ± 9.3	177.4 ± 21.1	171.0 ± 8.6

* Significant mean differences ($p < 0.05$) between groups (ANOVA); letters in bold signify which groups are similar to or different from each other (based on post hoc comparisons).

† XSA = estimated muscle cross-sectional area.

gin of the olecranon process of the ulna). Each measure was obtained in triplicate.

Skinfold measurements were taken from the anterior and posterior areas of both the upper arm and thigh on the right side (29). Skinfolds were measured in millimeters using Harpendon skinfold calipers. The measurements were taken in triplicate and averaged. The skinfold and circumference measurements were then used in the formula $(C - \Pi X)2/4\,\Pi$, where C = limb circumference and X = the average of one half the sum of the 2 skinfold measurements from the limb, to estimate muscle-plus-bone cross-sectional areas (10).

In addition, shoulder-to-elbow (acromion process to olecranon process), elbow-to-wrist (posterior point overlying the olecranon to the most distal palpable point of the styloid process of the radius), hip-to-knee (anterior aspect of the thigh between the inguinal crease and the proximal border of the patella), and knee-to-ankle (knee joint line and the tip of the medial malleolus) lengths and chest circumferences (level of the fourth costosternal joints, just superior to the nipples) were collected. This ensured that if the different groups of subjects differed statistically in body structure, then analysis of covariance could be used to account for these differences relative to measures of neuromuscular performance.

Statistical Analyses

The statistical analyses included the computation of descriptive statistics for each age group and each parameter of interest. Within a given day, between-trial reliability was determined by intraclass correlation coefficients, and if acceptable, the 3 trials were then averaged to produced one mean value for each day of testing. To determine the reproducibility between days, Pearson product-moment correlation coefficients were used to examine rank ordering effects, and dependent *t*-tests were performed to evaluate means differences between the days.

To determine group differences between age groups concerning parameters of interest, a one-way analysis of variance (ANOVA) was used. Where significant differences existed, a Tukey post hoc test was used to determined which groups were different. Finally, to examine the relationships between neuromuscular variables, Pearson product-moment correlation coefficients were determined within each age group for each muscle group location and between muscle group locations. Statistical significance was set a priori at a probability level of $p \leq 0.05$.

Results

Subject Characteristics

Table 1 depicts the mean and *SEM* and ANOVA results for age, height, body weight, percent fat, fat-free weight, and estimated cross-sectional areas for the upper arm and thigh for each age group. Each of the age groups were similar in terms of standing height and body weight. Additionally, the mean age for each age group indicated that a good representation of the age groups was obtained.

Percent body fat increased significantly as the subjects increased in age. The youngest age group had a percent body fat of 21.4%, the 35–40-year-old group had an average of 28%, and the oldest group averaged 32.5%. There was a slight downward age-related trend

Table 2. Upper- and lower-body neuromuscular parameters (mean ± *SEM*) for each age group.

	20–25 y	35–40 y	50–65 y
Bench press			
1RM (kg)*,†	77.1 ± 6.8 ***ab***	86.5 ± 8.2 ***a***	62.3 ± 6.7 ***b***
AP (W)†	223.3 ± 16.9 ***ab***	266.4 ± 29.4 ***a***	174.8 ± 22.2 ***b***
1/3P (W)	121.7 ± 9.8	140.2 ± 46.9	93.4 ± 27.2
2/3P (W)	356.3 ± 32.3	394.1 ± 44.6	280.9 ± 14.2
3/3P (W)†	188.8 ± 17.9 ***a***	256.1 ± 28.5 ***b***	141.2 ± 13.6 ***a***
PP (W)†	451.5 ± 39.2 ***a***	504.1 ± 57.8 ***a***	343.4 ± 21.2 ***b***
TTP (s)	0.60 ± 0.03	0.67 ± 0.14	0.55 ± 0.07
TT (s)	0.88 ± 0.02	0.98 ± 0.06	0.95 ± 0.03
Leg press			
1RM (kg)†	271.2 ± 15.4 ***ab***	292.7 ± 22.6 ***a***	224.2 ± 29.0 ***b***
AP (W)†	493.2 ± 37.3 ***ab***	551.1 ± 47.7 ***a***	363.1 ± 54.5 ***b***
1/3P (W)	204.9 ± 12.9	215.3 ± 20.4	170.5 ± 24.3
2/3P (W)	807.6 ± 73.7	855.1 ± 71.1	583.7 ± 93.5
3/3P (W)†	456.7 ± 35.0 ***ab***	511.6 ± 59.0 ***a***	307.7 ± 52.3 ***b***
PP (W)†	996.9 ± 91.9 ***a***	1,085.8 ± 101.1 ***a***	642.4 ± 123.5 ***b***
TTP (s)	0.55 ± 0.10	0.55 ± 0.08	0.48 ± 0.12
TT (s)	0.90 ± 0.04	0.86 ± 0.03	0.84 ± 0.10

*RM = repetition maximum; AP = average power; 1/3P = power generated during the first third of the lift; 2/3P = power generated during the middle third; 3/3P = power generated during the last third; PP = peak power; TTP = time to peak power; TT = total time.

† Significant mean differences ($p < 0.05$) between groups (ANOVA); letters in bold signify which groups are similar to or different from each other (based on post hoc comparisons).

for fat-free body mass from 63.8 to 57.3 kg, yet all groups were statistically similar with respect to fat-free body and for upper arm and thigh cross-sectional areas. All other anthropometrical measures that accounted for various limb lengths were also similar for the 3 groups ($p > 0.05$).

Neuromuscular Parameters (Strength and Power)

Statistical analyses indicated that all trials during both days of testing could be averaged to provide a more stable measure of each variable for each day. Table 2 shows the results from the one-way ANOVA and the Tukey post hoc determinations for the age group comparisons regarding the averaged neuromuscular variables.

Upper Body

When examining the upper-body parameters associated with the bench press, 4 of the 8 parameters were found to be significantly different between the 3 age groups. The 35–40-year-old group was significantly ($p < 0.05$) stronger than the oldest group (86.5 vs. 62.3 kg) and produced a greater amount of AP over the entire lift ($p < 0.05$; 266.4 vs. 174.8 W). In each instance, the youngest group, aged 20–25 years, was similar to the other 2 age groups. The power output during the last third of the bench press was significantly higher ($p < 0.01$) for the 35–40-year-old men when compared with the youngest and oldest groups (256.1 vs. 188.8 and 141.2 W, respectively). Also, the youngest 2 groups, aged 20–25 years and 35–40 years, had significantly greater ($p < 0.05$) PP values than the oldest group of men (451.5 and 504.1, respectively, vs. 343.3 W).

Lower Body

Similar results were obtained for the lower-body parameters associated with the leg press. Again, the same 4 of 8 parameters were found to be significantly different between the 3 age groups. The group aged 35–40 years was significantly ($p < 0.05$) stronger than the oldest men (292.7 vs. 224.2 kg) and produced a greater amount of AP over the lift ($p < 0.05$; 551.1 vs. 363.1 W). In each instance, the youngest men were similar to the other 2 age groups. Power output during the last third of the leg press was significantly higher ($p < 0.05$) for the 35–40-year-old men when compared with power output for the oldest group (511.6 vs. 307.7 W). Also, the groups aged 20–25 years and 35–40 years had significantly greater ($p < 0.05$) PP values than the men aged 50–65 years (996.9 and 1085.8, respectively, vs. 642.4 W).

Strength and Power Relationships

Tables 3–5 show the relationships between the measures of strength and power within each muscle group and between the upper- and lower-body locations for the 3 different age groups. There were stronger relationships between strength (1RM) and AP and PP for the upper body ($r = 0.80$ and 0.76) when compared

Table 3. Bench press power correlations for each age group.*

	1RM†	AP	1/3P	2/3P	3/3P	PP	TTP
AP							
20–25 y	0.80						
30–35 y	0.40						
50–65 y	0.81						
1/3P							
20–25 y		0.91					
30–35 y		0.92					
50–65 y		0.53					
2/3P							
20–25 y		0.93	0.86				
30–35 y		0.97	0.88				
50–65 y		0.88	0.47				
3/3P							
20–25 y		0.59	0.32	0.32			
30–35 y		0.97	0.89	0.88			
50–65 y		0.56	−0.22	0.23			
PP							
20–25 y	0.76	0.98	0.87	0.96	0.54		
30–35 y	0.40	0.99	0.84	0.95	0.96		
50–65 y	0.76	0.82	0.02	0.65	0.81		
TTP							
20–25 y		−0.06	−0.11	−0.39	0.56	−0.18	
30–35 y		−0.44	0.32	−0.49	−0.28	−0.38	
50–65 y		−0.18	−0.63	−0.45	0.55	0.32	
TT							
20–25 y		−0.25	−0.11	−0.25	−0.21	−0.22	−0.17
30–35 y		−0.37	0.21	−0.44	−0.37	0.97	0.97
50–65 y		−0.56	−0.06	−0.62	−0.48	−0.72	0.11

* Pearson correlation coefficients are significant ($p < 0.05$) under the following conditions: men aged 20 to 25 years, $n = 10$; $r > 0.602$; men aged 30 to 35 years, $n = 8$; $r > 0.632$; men aged 50 to 65 years, $n = 7$; $r > 0.707$.

† RM = One repetition maximum (strength in kg). AP = average power (W); 1/3P = power generated during the first third of the lift (W); 2/3P = power generated during the second third of the lift (W); 3/3P = power generated during the last third of the lift (W); PP = peak power (W); TTP = time to peak power (seconds); TT = total time for the lift (seconds).

with the lower-body relationships ($r = 0.56$ and 0.45) for the men aged 20–25 years. In general, the relationships were stronger between total measures of power (AP and PP) than measures of power for the 3 different phases of each lift (1/3P, 2/3P, and 3/3P). There were only weak relationships between measures of time and measures of power. All relationships between upper- and lower-body power and time variables were only moderately strong ($r = 0.32$–0.64).

Different from the youngest men, the relationships between strength and power for the men aged 35–40 years were stronger for the lower body ($r = 0.98$ and 0.93) when compared with the upper body ($r = 0.40$ and 0.40). All relationships were generally stronger for the men aged 35 to 40 years when compared with the youngest group; however, once again, measures between the upper- and lower-body muscle groups were only moderate related with the exception of the strength variable ($r = 0.88$).

The results for the oldest men, aged 50–65 years, were similar to the young men in that there were stronger relationships between strength and power for the upper body ($r = 0.81$ and 0.76) than for the lower body ($r = 0.62$ and 0.42). The oldest age group's correlation coefficients were stronger for the upper-body muscle group (bench press) than for the lower body (leg press). Again, correlation coefficients between the upper- and lower-body power measures were only moderate ($r = 0.39$–0.73).

Discussion

The groups were similar in respect to standing height, body weight, and all other anthropometrical parame-

Table 4. Leg press power correlations for each age group.*

	1RM†	AP	1/3P	2/3P	3/3P	PP	TTP
AP							
20–25 y	0.56						
30–35 y	0.98						
50–65 y	0.62						
1/3P							
20–25 y		0.76					
30–35 y		0.69					
50–65 y		0.90					
2/3P							
20–25 y		0.96	0.69				
30–35 y		0.99	0.66				
50–65 y		0.97	0.92				
3/3P							
20–25 y		0.81	0.64	0.48			
30–35 y		0.87	0.60	0.84			
50–65 y		0.95	0.75	0.90			
PP							
20–25 y	0.45	0.96	0.64	0.99	0.55		
30–35 y	0.93	0.97	0.50	0.97	0.86		
50–65 y	0.42	0.96	0.92	0.99	0.75		
TTP							
20–25 y		−0.25	0.13	−0.49	0.26	−0.44	
30–35 y		−0.16	0.20	−0.30	0.09	0.29	
50–65 y		−0.10	−0.34	−0.26	0.27	−0.36	
TT							
20–25 y		−0.03	0.34	−0.26	0.39	−0.21	0.95
30–35 y		−0.18	0.40	−0.26	0.08	−0.32	0.95
50–65 y		−0.14	−0.25	−0.28	0.13	−0.38	0.91

* Pearson correlation coefficients are significant ($p < 0.05$) under the following conditions: men aged 20 to 25 years, $n = 10$; $r > 0.602$; men aged 30 to 35 years, $n = 8$; $r > 0.632$; men aged 50 to 65 years, $n = 7$; $r > 0.707$.
† RM = One repetition maximum (strength in kg). AP = average power (W); 1/3P = power generated during the first third of the lift (W); 2/3P = power generated during the second third of the lift (W); 3/3P = power generated during the last third of the lift (W); PP = peak power (W); TTP = time to peak power (seconds); TT = total time for the lift (seconds).

Table 5. Correlations between bench press and leg press for each age group.*

	1RM†	AP	1/3P	2/3P	3/3P	PP	TTP	TT
20–25 y	0.54	0.57	0.83	0.64	0.11	0.58	0.32	−0.10
30–35 y	0.88	0.46	0.03	0.58	0.00	0.52	0.15	0.27
50–65 y	0.63	0.13	0.12	0.35	0.73	0.07	0.39	0.05

Footnotes * and † are identical to those that appear in Table 4.

ters involving girths, lengths, and cross-sectional areas. The values for cross-sectional areas of the upper arm and thigh were similar to values reported in the literature (10). Percent body fat increased significantly as the subjects increased in age and reflected purported milestones in the body's aging process as reported in the literature (23, 24, 34).

The day-to-day reliability for measures of strength and power were similar for each age group. One might have expected the oldest group to be more variable in their day-to-day ability to produce power or exert strength because of the associated age-related changes in neuromuscular function, but this was not the case.

In general, there was better reliability for measures of the upper body when compared with the lower body across all age groups, but again, all parameters were reproducible and similar to values reported in the literature (14, 34, 35). The middle-aged group (35–40 years) was able to exert as much force (1RM) for both the upper- and lower-body muscle groups as the youngest men and significantly more force than the oldest group. Additionally, this middle group produced significantly higher AP and PP values than the oldest group (50–65 years). One might have expected the youngest group (20–25 years) to be the strongest according to other research (16, 25); however, a number of articles suggest that strength can be maintained from age 20 years until about age 50 years (18, 19, 25). One possible explanation could be that in this group of untrained men perhaps the youngest group may not have been able to fully activate their total muscle mass. It is clear that human voluntary strength is determined not only by the quantity (muscle cross-sectional area) and quality (fiber types) of the involved muscle mass, but also by the extent to which the muscle mass has been activated (neural factors) (31). Another possibility may be that the oldest group was in better physical condition than the general age-matched population, since there is always a fitness-related bias introduced into any study that solicits volunteers and then assesses physical capacity.

There is little literature to support or deny the findings of the power results in this study, but since maximum strength is needed to achieve maximum power, it can be assumed there is some sort of direct relationship between them (36). Similar to the strength results, the literature shows that one might expect the younger groups to have a greater PP than the older group, because of the fact that there are fewer type II (power) fibers and these fibers become smaller as subjects age (6, 26). Also, Tomlinson and Irving (40) reported that fiber-type grouping, a loss of the type II motor units (those motor units responsible for innervating the fibers primarily used for strength and power) and an increase in fiber density in the type I motor units (those motor units responsible for innervating the fibers primarily used for muscular endurance), begins at about 60 years of age (11).

It is also possible that since it has been suggested that fiber number reaches a maximum at approximately 25 years of age and then decreases by approximately 40% by age 80 years (6, 11, 18, 28), none of the younger subjects had reached their potential for the maximum number of fibers; whereas, the 35–40-year-old group had reached their maximum but had not yet lost any fibers or had a fiber-type shift as the older group may have experienced (27).

When examining the relationships between strength and power within each of the age groups, care should be taken when interpreting correlation coefficients with such small sample sizes. However, for the given set of subjects, the data revealed stronger relationships for the upper body for the youngest and oldest age groups (20–25 and 50–65 years, respectively) when compared with the strength-power relationship for the lower body. The men aged 30 to 35 years had a stronger strength-power relationship for the lower body than for the upper body in contrast to the other 2 groups. These findings may be purely coincidental, since it is difficult to offer a physiological explanation for these differences.

The strength-power relationships between the upper and lower body within each group were only moderate, indicating some independence between measures of strength and power for different muscle groups. The literature seems to support the concept that strong muscles are powerful ones (21); however, this inherent relationship may weaken as skeletal muscle begins to age. If the older subjects begin to lose muscle mass and type II muscle fibers preferentially and there is a slowing of movement and reaction times (15) and an increase in intramuscular fat and connective tissue with increased age, one might expect a loss in the ability to coordinate the musculature that is still present, therefore weakening the relationship between strength (muscle mass activated) and power (coordination of activation).

In summary, the older subjects had a higher percent body fat and lower body density than their younger counterparts. Since most everyday tasks require movement, the ability of muscles to generate and sustain power is of great consequence (5). Within the context of this study, strength and power were greater for the youngest 2 age groups; however, the 2 expressions of neuromuscular performance demonstrated only moderate relationships when these neuromuscular parameters were evaluated for the oldest men (50–65 years). It appears that muscle tends to act in a rather independent fashion with respect to the concepts of strength and power, especially when considering muscle groups of the upper and lower body. It should also be remembered that correlational information does not provide evidence for cause and effect so care should be used when interpreting these relationships.

Practical Applications

The design of appropriate resistance training programs for the elderly or for individuals at potentially critical periods, i.e., 45 years of age, 60 years of age, etc., could slow down the functional consequences of an aging neuromuscular system. For example, based on whole body potassium and total body water studies, the age of 45 years represents a critical period for the significant loss of fat-free tissue (muscle) and a concomitant lowering of basal metabolism. These individuals could be targeted for a resistance training program that would emphasize the gaining of fat-free mass (muscle hypertrophy). Since the relationship between strength and power is reasonable for this age group, the emphasis would be placed on the gaining or maintenance of muscle mass. For the older adult (≥65 years) perhaps the focus could be on lighter weights that could be moved more quickly to maximize power output and an additional emphasis on maintaining or improving muscular endurance through resistance training programs. In fact, emphasis on strength, power, or muscular endurance could all be incorporated into an overall resistance training program, regardless of age, with the introduction of periodization.

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