

Muscle function in elite master weightlifters

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ABSTRACT

PEARSON, S. J., A. YOUNG, A. MACALUSO, G. DEVITO, M. A. NIMMO, M. COBBOLD, and S. D. R. HARRIDGE. Muscle function in elite master weightlifters. *Med. Sci. Sports Exerc.*, Vol. 34, No. 7, pp. 1199–1206, 2002. **Purpose:** To determine whether explosive power and isometric strength of the lower-limb muscles in elite master Olympic weightlifters declines at a similar rate to nontrained healthy controls with increasing age. **Methods:** 54 elite level masters weightlifters (aged 40–87), who were competitors at the World Masters Weightlifting Championships (1999), were compared with a similar number of aged-matched, healthy untrained individuals. Isometric knee extensor strength and lower-limb explosive power were tested. Extent of antagonist co-contraction during isometric knee extension was determined by EMG and power loading characteristics by using a variable inertial system. Muscle volume was estimated using anthropometry. **Results:** On average, the weightlifters were able to generate 32% more peak power ($P < 0.05$) in the lower limbs and 32% more isometric knee extensor force ($P < 0.05$) than the control subjects. No significant differences in lower-leg volume were observed between the two groups. Peak power declined at a similar rate with increasing age in the weightlifters and controls (1.2 and 1.3% of a 45-yr-old's value per year), as did strength, but at a lower rate (0.6 and 0.5% per year). The inertial load at which the weightlifters achieved their maximal peak power output was greater ($P < 0.05$) than the controls. The torque generated at this optimal inertia was also greater in the weightlifters ($P < 0.05$), whereas the time taken for the weightlifters to reach their maximal peak power was on average 13% shorter ($P < 0.05$). No differences in antagonist co-contraction during isometric knee extension were observed between the two groups. **Conclusions:** Muscle power and isometric strength decline at a similar rate with increasing age in elite master weightlifters and healthy controls. In spite of inertial load optimization, muscle power declined in both groups at approximately twice the rate of isometric strength. Although similar rates of decline were observed, the absolute differences between the weightlifters and controls were such that an 85-yr-old weightlifter was as powerful as a 65-yr-old control subject. This would therefore represent an apparent age advantage of ~20 yr for the weightlifters. **Key Words:** MUSCLE, EXERCISE, WEIGHTLIFTING, AGEING, POWER, STRENGTH, SURFACE ELECTROMYOGRAPHY

The decline in maximal power generation with age has important implications for independent living in later life (2,13). It has been reported previously, using a fixed inertial loading device, that muscle power declines at twice the rate of isometric strength with increasing age (13). The mechanisms underlying such a phenomenon are unclear. One possible explanation might be that a lack of optimization of inertial loading results in slower and less powerful contractions in weaker, older subjects. Studying master weightlifters who have maintained high levels of physical training for many years may aid in our understanding of the potential limits to which older muscles may function. In this cross-sectional study, the strength and power of the lower-limb muscles was measured in 54 master weightlifters who were competitors at the World Masters Weightlifting Championships (Glasgow, U.K., 1999). Their data were compared with those obtained subsequently from healthy, but nontrained, age-matched subjects. The youngest competitor was 40 and the oldest 87 yr of age. The main

aim of the present study was to determine whether elite master Olympic weightlifters show similar age-related declines in muscle strength and power as healthy nontrained individuals of a similar age.

APPROACH TO THE PROBLEM

In contrast to standard resistance training, the sport of Olympic weightlifting, which comprises two disciplines—the clean and jerk and the snatch, involves strength, power, and large motor-skill elements. The weightlifter is required to accelerate rapidly and brake large inertial loads and to coordinate the movement to complete the lifts correctly. For obvious technical and safety reasons, Olympic weightlifting does not lend itself as a tool for comparing objectively muscle function of master weightlifters with that of untrained older subjects. Therefore, in the present study we have compared muscle function between these master weightlifters and nontrained older individuals in terms of maximum isometric knee-extensor strength and in terms of lower-limb power. Lower-limb power was tested using a multi-joint testing system (Fig. 1), which was modified to allow optimization of inertial loading (12). This apparatus is designed for safely measuring explosive power in older people (1). The power values in this apparatus have been

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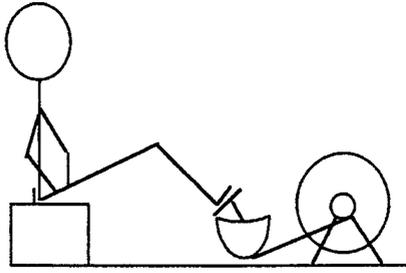


FIGURE 1—Diagram showing subject positioning for the inertial power test (1).

shown to relate closely to the ability to perform functional tasks in older people (2). This apparatus also had the advantage of being unfamiliar to both groups. It was hypothesized that, as the nature of Olympic weightlifting involves the rapid acceleration of large inertial loads and the generation of high power outputs, these weightlifters would exhibit superior dynamic muscle function characteristics even when tested in an unfamiliar piece of apparatus when compared with age matched controls. It was also hypothesized that in light of this ability to generate high power the rates of decline in muscle power output would be less than that of untrained subjects and also that by being stronger the weightlifters would require higher inertial loads to express their maximal power output than their untrained counterparts. In addition, knee extensor strength was measured using isometric dynamometry to establish whether the rate of decline differed to that of power and also to evaluate the degree of co-contraction during isometric knee extension.

METHODS

Subjects. A field laboratory was established close to the competition warm-up area at the World Masters Weightlifting Championships held in Glasgow, United Kingdom (1999). Fifty-four male competitors volunteered to take part in the study. Data obtained at this meeting were compared with data subsequently obtained on a similar number of untrained healthy men defined using the criteria of Greig et al. (5). The physical characteristics of the subjects are shown in Table 1. All subjects were informed of the testing procedures before testing and signed a consent form agreeing to take part in the study. The study had the approval of Strathclyde University and the Royal Free Hospital Ethics committees and was in agreement with the policy statement regarding human subjects of the American College of Sports Medicine.

Power testing. All exertions of the preferred lower limb were carried out with the subjects seated as previously described (12) shown in Figure 1. Test-retest data of peak muscle power in young subjects have shown a CV of 3.3% (12). Briefly, the tests consisted of the subject being seated in an upright position in the dynamometer with the knee flexed, a seat belt was attached across the hips securing them into the seat. The dynamometer, which has a very low backrest (10 cm) to minimize the possibility of utilizing the

back extensor muscles in the exertion, comprised an inertial flywheel linked to a pedal assembly via a chain and free-wheel mechanism. The exertion consisted of performing a single maximal leg thrust against the pedal. The subjects were actively encouraged to give their maximal effort. A total of 18 exertions were recorded, three trials at each of six inertial loads ranging in order from 0.024–0.543 kg·m⁻². The highest recorded value of peak power from the 18 contractions was taken as maximal peak power (MPP). Subsequently, the torque (TQ_{mpp}) and velocity (V_{mpp}) generated at MPP as well as the time taken to reach MPP were determined. The average power (AP_{mpp}) generated at this inertia was also calculated. Power measurements were made by measuring the torque and displacement of the inertial wheel. The torque applied to the wheel was determined via a strain gauge located in the chain and was amplified via a purpose-built strain-gauge amplifier. A rotary encoder, which was mounted end on to the shaft, detected displacement of the inertial wheel. Both analog and digital signals were then sampled by an A/D converter (CED micro1401, Cambridge, U.K.). Analysis of the power data was carried out with a mathematical software package (Mathcad Ver. 7 Mathssoft, Cambridge, MA); this procedure has been described in detail elsewhere (12). Data were then fitted using second-order polynomial techniques to allow velocity data to be calculated. Power was then calculated as the product of torque and velocity.

Isometric knee extensor strength. The isometric strength tests were performed on the same limb as that tested on the power dynamometer. The subject was seated upright with the knee flexed at 90° to the horizontal. The ankle was fixed in a restraining collar, which was attached to a non-extensible rod attached to a strain-gauge assembly. The force transducer signal was amplified as above and sampled by an A/D system (CED 1401 Cambridge, U.K.) at 2 kHz. Each subject carried out a total of three isometric knee extension efforts and three isometric knee flexion efforts. In all tests, the subjects were actively encouraged to give their maximal effort, and a 1-min rest period was given between contractions. In all cases, the test order was first power testing and second strength testing.

SEMG. Simultaneous recording of the sEMG activity from the vastus lateralis and the long head of the biceps femoris muscles was made during the measure of isometric strength. The assumption was made that these two muscles were representative of their constituent groups (3). Before mounting the recording electrodes, the skin surface was prepared by light abrasion and cleaning with alcohol swabs. Two silver/silver chloride bipolar electrodes (Medicotest, type N-10A, St. Ives, U.K.), with a 20-mm interelectrode distance (center to center) were placed midline on the muscle belly halfway between the center of the belly and the distal myotendinous junction of the prepared site of the muscles. A ground electrode (Dantec Electronics, mod. 13S97, Bristol, U.K.) was placed around the ankle of the contralateral limb. The sEMG was band pass filtered between 3 and 1000 Hz (Neurolog Filter NL 125, Digitimer, Welwyn Garden City, U.K.), preamplified ($\times 1000$) (Neu-

TABLE 1. Physical characteristics of the subjects; all table values shown as mean \pm SE; significant difference from control are shown (*).

| | Age Group (yr) | | | | |
|--------------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| | 40-49 (N = 10) | 50-59 (N = 11) | 60-69 (N = 16) | 70-79 (N = 13) | 80-89 (N = 4) |
| Age (yr) | | | | | |
| Control | 45.4 (\pm 0.9) | 53.1 (\pm 0.7) | 64.2 (\pm 0.8) | 74.5 (\pm 0.7) | 84.3 (\pm 1.4) |
| Weightlifter | 42.7 (\pm 0.6) | 53.9 (\pm 0.8) | 64.1 (\pm 0.7) | 74.3 (\pm 0.8) | 84.2 (\pm 1.5) |
| Body mass (kg) | | | | | |
| Control | 75.7 (\pm 2.4) | 76.6 (\pm 2.3) | 77.0 (\pm 2.3) | 72.7 (\pm 2.2) | 68.6 (\pm 7.5) |
| Weightlifter | 87.0 (\pm 7.8) | 83.0 (\pm 4.6) | 78.0 (\pm 2.8) | 77.6 (\pm 3.5) | 72.0 (\pm 6.5) |
| Height (cm) | | | | | |
| Control | 177.1 (\pm 2.3) | 177.8 (\pm 2.4) | 174.8 (\pm 1.5) | 171.9 (\pm 1.5) | 167.7 (\pm 3.5) |
| Weightlifter | 173.6 (\pm 2.7) | 167.8* (\pm 1.6) | 168.3 (\pm 1.9) | 167.2 (\pm 1.7) | 164.3 (\pm 2.5) |
| Total lower-limb volume (cm ³) | | | | | |
| Control | 8734.8 (\pm 276.3) | 8903 (\pm 366.9) | 8676.2 (\pm 241.5) | 7706.3 (\pm 297.7) | 7911.2 (\pm 507.9) |
| Weightlifter | 8680.2 (\pm 831) | 7846.5 (\pm 312.8) | 7626.3 (\pm 365.3) | 7318.6 (\pm 345.8) | 6816.1 (\pm 524.1) |
| Lean lower-limb volume (cm ³) | | | | | |
| Control | 6159.8 (\pm 287.5) | 6341.1 (\pm 298.0) | 6103.5 (\pm 200.5) | 5370.8 (\pm 251.2) | 5359.0 (\pm 322.6) |
| Weightlifter | 7276.6 (\pm 830.7) | 6490.0 (\pm 350.7) | 6077.9 (\pm 300.7) | 5477.1 (\pm 305.1) | 4854.6 (\pm 508.1) |

rolog remote AC preamplifier NL 824) amplified ($\times 2$) (Neurolog Isolation amplifier NL 820), and A-D converted (type 1401, CED, Cambridge, U.K.) at a sampling rate of 2048 Hz. To quantify the sEMG amplitude (RMS) and frequency (MDF) components, computer-aided analysis was performed over a 1-s window of the plateau phase during the isometric effort. The spectral parameters were evaluated by standard fast Fourier transforms over 2048 samples. This procedure has been described in detail elsewhere (10). MDF was adopted as a single measure to represent the power spectrum, because of its lower sensitivity to noise with respect to the mean frequency (MNF) (14). Percentage co-contraction during isometric knee extension was defined as the RMS sEMG of the biceps femoris during maximal voluntary isometric extension, divided by the RMS sEMG activity of the biceps femoris during maximal voluntary isometric flexion.

Anthropometry. Lower-limb volume was estimated from anthropometric measurements comprising segmental circumferences and lengths as described by Jones and Pearson (8). Skin-fold measurements were made at four sites: anterior, posterior mid-thigh and lateral, medial mid-calf by using skin callipers (John Bull Ltd. West Sussex, U.K.). Skin-fold corrections were made using the following regression equations (personal communication, Professor P. R. M. Pearson), anterior thigh ($y = 1.0142 + 0.557 \times \text{skin-fold value}$), posterior thigh ($y = 1.368 + 0.532 \times \text{skin-fold value}$), medial calf ($y = 0.985 + 0.499 \times \text{skin-fold value}$) and lateral calf ($0.8701 + 0.3926 \times \text{skin-fold value}$). Where y represents the corrected skin-fold value used in the calculations.

Data analysis. All data analysis was carried out using SPSS version 10. Data are presented as means \pm SE. For clarity, the subjects were assigned to decades (see Tables 1 and 2). Multiple Student's t -tests were applied to the data presented in Tables 1 and 2 and corrected for multiple comparisons by using the Bonferroni method. Statistical comparisons between the weightlifters and untrained subjects with respect to age for the variables measured were made using a general linear model and univariate analysis (ANOVA). For descriptive purposes linear regression analysis was also performed on each group to determine the rate of change with age. Interpolated values at 45 yr of age and 85 yr of age were calculated using these regression equations. For between-group comparisons, for the inertial load at which peak power occurred, a Student's t -test was performed. Levels of significance for all tests were set at $P < 0.05$.

RESULTS

The physical characteristics of the subjects are shown in Table 1. No significant differences were observed in body mass, height (apart from the 50-59 age group), age, and total and lean lower-limb volume between the two groups. However, there is a tendency for the untrained subjects to have higher total lower-limb volumes at all age groups and conversely for the weightlifters to have higher lean lower-limb volumes (muscle and bone) at most age groups. Figure 2 shows the lift performance data from the 1999 World Championships for the competitors tested. Of the 54 competitors tested, 15 were winners of their respective age and

TABLE 2. Mean values for isometric knee extensor strength, MPP and AP_{mpp}; significant differences from controls are shown (*).

| | Age Group (yr) | | | | |
|------------------------|-----------------------|----------------------|----------------------|----------------------|---------------------|
| | 40-49 (N = 10) | 50-59 (N = 9,11) | 60-69 (N = 16) | 70-79 (N = 13) | 80-89 (N = 4) |
| MPP (W) | | | | | |
| Control | 653.1 (\pm 44.1) | 561.4 (\pm 38.7) | 549.4 (\pm 39.2) | 442.1 (\pm 37.7) | 242.6 (\pm 22.9) |
| Weightlifter | 1028.4 (\pm 75.4)* | 879.9 (\pm 79.4)* | 811.7 (\pm 45.1)* | 600.9 (\pm 38.5)* | 456.0 (\pm 89.5) |
| AP _{mpp} (W) | | | | | |
| Control | 299.5 (\pm 20.2) | 248.7 (\pm 16.3) | 246.7 (\pm 20.3) | 204.2 (\pm 15.8) | 88.1 (\pm 19.7) |
| Weightlifter | 438.6 (\pm 38.2)* | 404.0 (\pm 41.3)* | 384.4 (\pm 23.7)* | 282.7 (\pm 21.3)* | 214.5 (\pm 38.3) |
| Isometric strength (N) | | | | | |
| Control | 313.1 (\pm 42.1) | 481.3 (\pm 53.5) | 422.7 (\pm 31.9) | 321.8 (\pm 48.2) | 238.4 (\pm 55.6) |
| Weightlifter | 617.3 (\pm 51.9)* | 565.4 (\pm 45.2) | 601.3 (\pm 34.8)* | 438.4 (\pm 26.2) | 519.6 (\pm 57.2) |

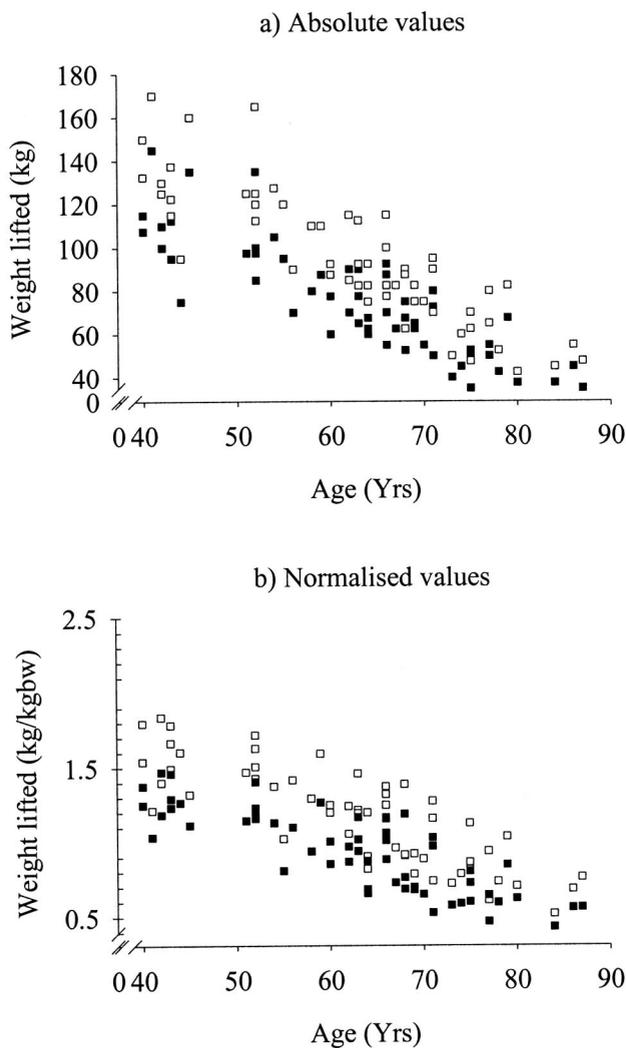


FIGURE 2—Performance data for all weightlifters tested (Glasgow World Masters Weightlifting Championships 1999). Clean and jerk (□), snatch (■). Regression of clean and jerk with age, $y = -2.1 \cdot (\text{age}) + 223.86$ ($R^2 = 0.45$), and for the snatch, $y = -1.7 \cdot (\text{age}) + 181.34$ ($R^2 = 0.47$). Regression of clean and jerk normalized to body weight with age, $y = -2.2 \cdot 10^{-2}(\text{age}) + 2.6$ ($R^2 = 0.64$) and for the normalized snatch, $y = -1.8 \cdot 10^{-2}(\text{age}) + 2.1$ ($R^2 = 0.67$).

weight categories. A further 11 were silver medallists, and 16 others were bronze medal winners.

The values of MPP and AP_{mpp} can be seen in Figure 3 and are summarized by age group in Table 2. Both MPP and AP_{mpp} declined as a function of age in both groups, and there was no significant difference between the groups in rate of decline of MPP ($R^2 = 0.54$, $P < 0.05$) or AP_{mpp} ($R^2 = 0.48$, $P < 0.05$) (see Table 3). On average, the weightlifters generated 35% more AP_{mpp} ($P < 0.05$) and 32% more MPP ($P < 0.05$) than the control subjects. Normalization of power values with respect to body mass or lean lower-limb volume made no significant difference to age-related or group-related differences. The difference in decline of MPP between the two groups was $4.5 \text{ W} \cdot \text{yr}^{-1}$, and the 95% CI for the difference was -0.67 – $10.04 \text{ W} \cdot \text{yr}^{-1}$. Therefore, it is unlikely that the weightlifters would have declined more than $10 \text{ W} \cdot \text{yr}^{-1}$ greater than the controls.

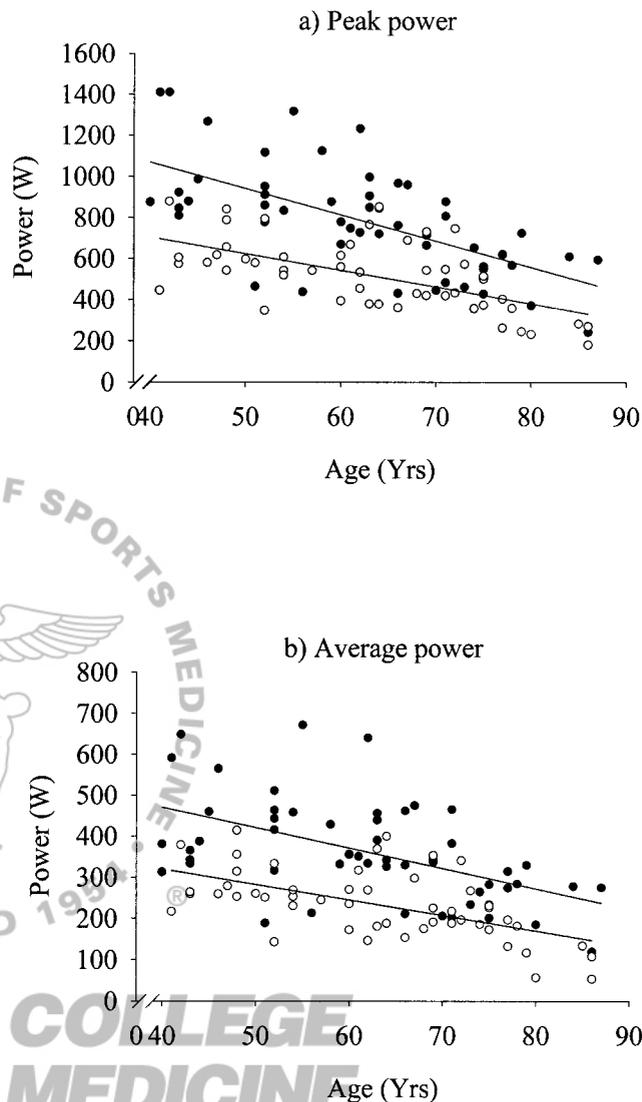


FIGURE 3—Absolute values for a) MPP and b) AP_{mpp} . Control (○), weightlifters (●). Values for MPP regression lines $y = -8.1 \cdot \text{age} + 1029.2$ and $y = -12.8 \cdot \text{age} + 1580.7$ for the controls and weightlifters, respectively. Values for the regression lines for AP_{mpp} $y = -3.8 \cdot \text{age} + 471$ and $y = -4.9 \cdot \text{age} + 669.1$ for the controls and weightlifters, respectively.

A statistically calculated power of 0.8 was shown to be sufficient to show a difference in rate of decline of $8.11 \text{ W} \cdot \text{yr}^{-1}$.

Figure 4 illustrates the number of subjects generating MPP at each of the inertial loads tested. Overall, the weightlifters required a higher inertia to express their MPP than the control subjects ($P < 0.05$). The torque (TQ_{mpp}) and velocity (V_{mpp}) generated at MPP are shown in Figures 5a and b. Figure 4c shows the time taken to reach MPP (T_{mpp}). TQ_{mpp} declined with increasing age in both groups ($R^2 = 0.49$, $P < 0.05$), but the rates of decline were not significantly different between the two groups. On average, the levels of TQ_{mpp} generated by the weightlifters were 34% greater ($P < 0.05$) than those of their untrained counterparts. V_{mpp} declined significantly with age for both groups, and on average there was no significant difference between the two groups. T_{mpp} increased with age in both the weightlifters

TABLE 3. The percentage difference between the mean values of the weightlifters with respect to the control subjects is shown in column I; the age-related decline for both groups, in absolute units per year is shown in columns II and III; the age-related decline for both groups in relative units per year (expressed as a percentage of a 45-yr-old value is shown in columns IV-V; the percentage value of an 85-yr-old relative to that of a 45-yr-old is shown in columns VI-VII.

| | I) Average % Difference between Groups | II) Weightlifter Absolute Rate Change | III) Control Absolute Rate Change | IV) Weightlifter Relative Rate Change | V) Control Relative Rate Change | VI) Weightlifter 85 yr-old as a % of a 45-yr-old | VII) Control 85 yr-old as a % of a 45-yr-old |
|--------------------------------------------------|----------------------------------------|---------------------------------------|-----------------------------------|---------------------------------------|---------------------------------|--------------------------------------------------|----------------------------------------------|
| Normalised clean & jerk (kg·kgbw ⁻¹) | N/A | 2.2·10 ⁻² | N/A | 1.4 | N/A | 44 | N/A |
| Normalised snatch (kg·kgbw ⁻¹) | N/A | 1.8·10 ⁻² | N/A | 1.4 | N/A | 44 | N/A |
| MPP (W) | 32* | 12.6† | 8.1† | 1.3 | 1.2 | 49 | 51 |
| AP _{mpp} (W) | 35* | 4.9† | 3.8† | 1.1 | 1.5 | 55 | 50 |
| TQ _{mpp} (Nm) | 34* | 0.29† | 0.2† | 0.9 | 1.0 | 60 | 59 |
| V _{mpp} (rads·s ⁻¹) | | 0.13† | 0.14† | 0.4 | 0.4 | 85 | 87 |
| T _{mpp} (s) | -13* | 1.3·10 ⁻³ † | 2.3·10 ⁻³ † | 0.5 | 0.8 | 80 | 70 |
| Isometric strength (N) | 32* | 3.4† | 1.9† | 0.6 | 0.5 | 78 | 81 |
| RMS (mV) | 53* | 7.7† | 0.51† | 0.9 | 0.1 | 64 | 94 |
| MDF (Hz) | 12* | 2.6·10 ⁻² | 0.15 | 3.9·10 ⁻⁵ | 0.2 | 98.3 | 90 |

* Weightlifters significantly different from controls ($P < 0.05$).

† Significant decline with age ($P < 0.05$).

and controls ($P < 0.05$), and on average the values of T_{mpp} were significantly lower for the weightlifters ($P < 0.05$).

The isometric extensor strength data are presented in Figure 6 and Table 2. Isometric strength declined with age in both the weightlifters and untrained controls ($R^2 = 0.29$, $P < 0.05$), but again there were no significant differences in the rates of decline of strength between the two groups (Table 3). On average, the weightlifters had significantly ($P < 0.05$) higher average values (32%) for isometric extensor strength.

The MDF of the sEMG is shown in Figure 7a. There was no effect of age on MDF in either group. However, weightlifters exhibited higher average values, $66.4 \text{ Hz} \pm 1.52$ as against $58.2 \text{ Hz} \pm 1.55$ for the control group ($P < 0.05$). Figure 7b shows the RMS values for the sEMG where there was a significant decline as a function of age ($R^2 = 0.40$, $P < 0.05$). On average, the weightlifters produced significantly higher values of RMS ($P < 0.05$). The activation of the biceps femoris muscles during isometric leg extension (i.e., co-contraction) expressed as a percentage of the maximum biceps femoris activity is shown in Figure 7c. No significant effects of age, rates of decline, or differences between the two groups were observed.

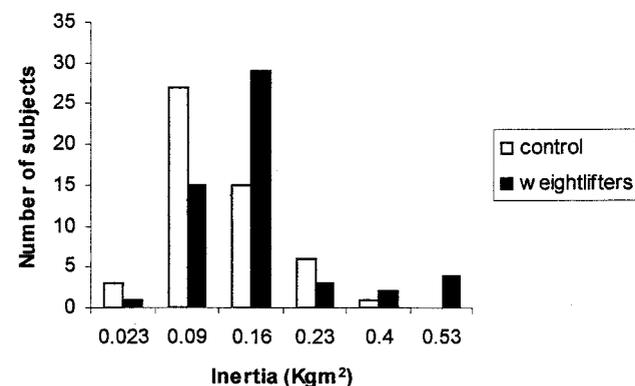


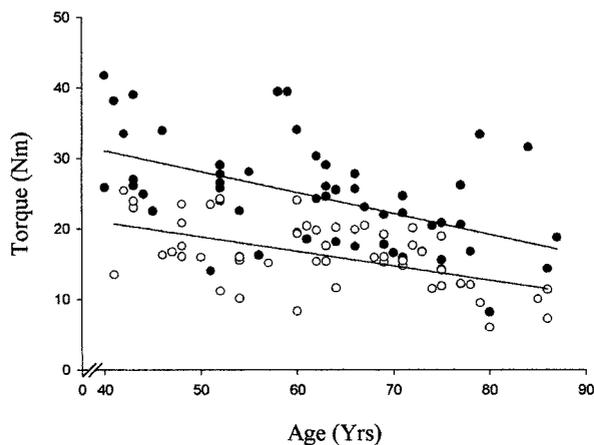
FIGURE 4—Histogram showing number of subjects obtaining MPP at a specific inertia. Weightlifters showing significantly higher values of inertia than controls at maximal peak power ($P < 0.05$).

DISCUSSION

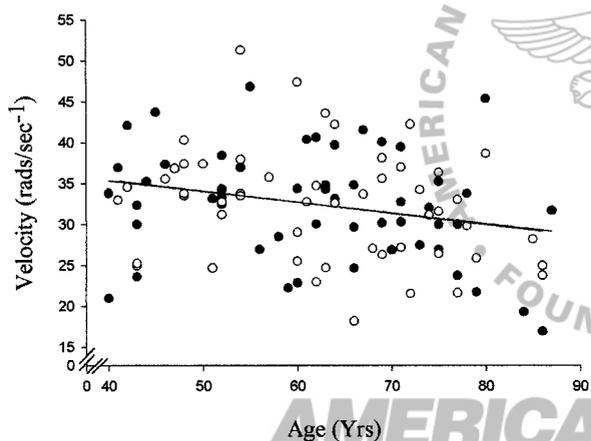
This study has compared explosive muscle power and isometric strength in the lower-limb muscles of elite master weightlifters with men of a similar age who were healthy but did not undertake any regular physical exercise. The main findings were that i) both strength and power declined with increasing age in both the weightlifters and the untrained subjects; ii) the relative rate of decline was similar for the two groups, with power declining at twice the rate of isometric strength, despite inertial load optimization; and iii) the weightlifters were significantly stronger and more powerful, requiring a higher level of inertia to generate their MPP. This was despite the fact that there was no detectable difference in lean lower-limb volume between the groups as estimated anthropometrically (Table 1).

The decline in the amount of weight that can be lifted in competitive performance in masters weightlifting has been previously documented (11). This decline is confirmed in the present study. Two of the competitors tested in the present study were winners in the 85-kg category and represented the extreme of age categories. The winner in the 80+ category, who was also the oldest competitor, lifted 55 kg in the clean and jerk. This amounted to 36% of the winning lift in the 40- to 44-yr-old age group (150 kg). From a functional perspective, it is worthy of note given that many older people of a similar age, i.e., over 80 yr of age struggle to rise from a chair let alone be able lift 55 kg above their heads.

In agreement with the decline in competition performance with increasing age is the observed decline in the performance of the tests of muscle function. In terms of peak muscle power generation, the data suggest a loss equivalent to 1.3% per annum for the weightlifters and 1.2% per annum for the controls. Skelton et al. (13) have previously reported a progressive decline in average power in healthy older people ranging in age from 65 to 85 yr of age. This was tested using a single inertial load. In another study of master athletes, Grassi et al. (4) measured power output by using double leg jumps from a force platform. They reported in



b) Velocity at MPP



c) Time to reach MPP

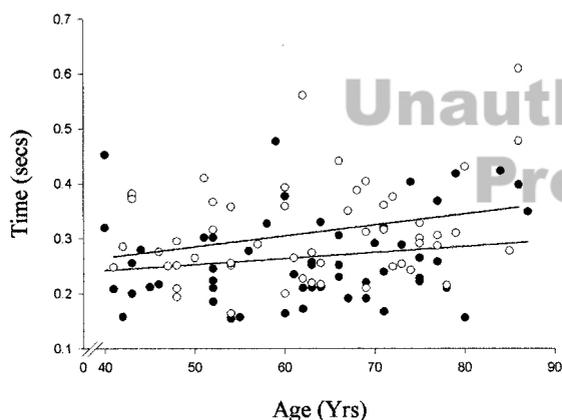


FIGURE 5—a) Torque (T_{mpp}), b) velocity (V_{mpp}), and c) time (T_{mpp}) values obtained at MPP. Controls (○) and weightlifters (●) Regression equation showing relationship between T_{mpp} and age for weightlifters $y = -2.96 \cdot 10^{-1} \cdot (\text{age}) + 42.955$ and for the controls $y = -2.05 \cdot 10^{-1} \cdot (\text{age}) + 29.153$. Regression equation showing relationship between V_{mpp} and age for weightlifters, $y = -1.31 \cdot 10^{-1} \cdot (\text{age}) + 40.623$ and for the controls $y = -1.35 \cdot 10^{-1} \cdot (\text{age}) + 40.358$. Regression equation showing relationship between T_{mpp} and age for weightlifters $y = -1.33 \cdot 10^{-3} \cdot (\text{age}) + 0.221$ and for the controls $y = -2.3 \cdot 10^{-3} \cdot (\text{age}) + 0.198$.

Isometric knee extensor strength

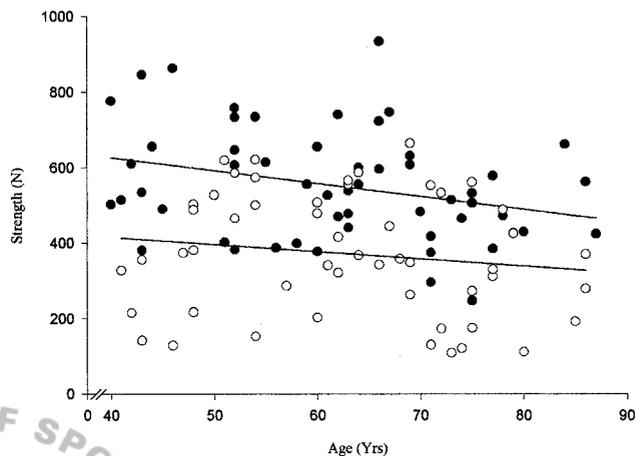
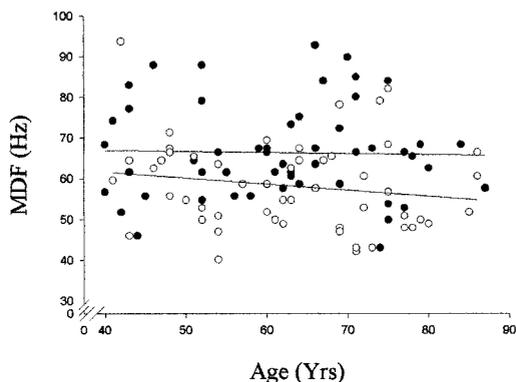


FIGURE 6—Isometric knee extensor strength. Controls (○), weightlifters (●). Regression equation for relationship between weightlifter absolute isometric strength and age, $y = -3.417 \cdot (\text{age}) + 763.04$ and for controls, $y = -1.89 \cdot (\text{age}) + 491.33$.

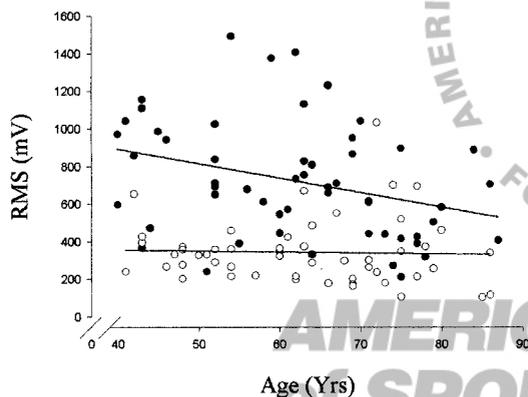
power athletes (sprinters and jumpers), ranging from a mean age of 17.7 yr to 74.3 yr, that peak power output of the lower limbs in the older subjects was approximately 50% of that seen in the younger subjects. They also reported that the maximum power output of the power athletes over the age of 70 was 58% of that generated by the subjects in the 40–49 age group. In general agreement, the results of the present study showed that the 70-yr-old weightlifters generated 62% of the power generated by the youngest weightlifter group. An important finding in the present study was that the decline with age in both average and peak power was similar for the weightlifters and the control subjects (Table 3). However, the weightlifters generated significantly greater absolute levels of both MPP and AP_{mpp} such that the power generated by an 85-yr-old competitor was equivalent to that of a 65-yr-old nontrained subject, representing an apparent gain of some 20 yr. This was also the case when the data were normalized to body mass or lower-limb volume.

A further finding of the present study was that the inertial load at which MPP occurred was higher in the weightlifters than the untrained group. It is likely that the weightlifters, because they are stronger, are better able to accelerate these higher inertial loads and therefore reach an optimal position on their power velocity relationship during the exertion. Weaker individuals, however, must use a greater proportion of their maximal strength to achieve a similar acceleration at a given inertial load. Due to the force-velocity relation, such a contraction must be performed more slowly and thus possibly on a less favorable portion of the power-velocity relationship. Therefore, a lower inertia is more favorable for the weaker subjects, for when MPP was broken down into its torque and velocity components, the velocity component was found to be not significantly different between the two groups (Fig. 5b). However, the torque generated by the weightlifters at their optimal inertia was significantly

a) MDF of the vastus lateralis during isometric knee extension



b) RMS of the vastus lateralis during isometric knee extension



c) Percentage cocontraction during isometric knee extension

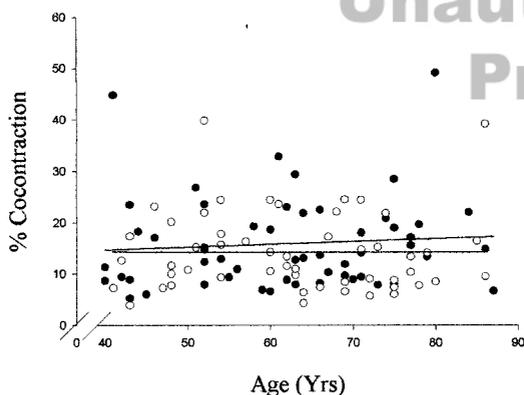


FIGURE 7—Plots of a) the mean density frequency (MDF) of the power spectrum of the vastus lateralis $y = -2.3 \cdot 10^{-2} \cdot (\text{age}) + 67.98$ and $y = -1.5 \cdot 10^{-1} \cdot (\text{age}) + 67.6$ represent the regression relationships with respect to age for the weightlifters and controls, respectively; b) the root mean squared (RMS) of the vastus lateralis during isometric knee extension; c) the percentage of biceps femoris involvement during isometric knee extension. Controls (○), weightlifters (●).

greater (Fig. 5a) than the torque generated by the control subjects at their lower optimal inertia. In addition, the weightlifters required significantly less time than the untrained group to reach MPP (Fig. 5c). Thus, not only are the master weightlifters achieving higher levels of MPP through higher torque generation, they are also generating torque more quickly.

No detailed anatomical measures were possible in the field setting described, nor was it possible to obtain muscle biopsy samples. However, earlier data on strength-trained older individuals might suggest a number of mechanisms explaining their superior muscle function. These include a greater lean-leg volume (6), a relatively greater size of their Type II fibers (9), and that strength-trained individuals have been shown to have a larger Type II fiber area (15), although a training adaptation toward faster contracting fibers expressing the same MHC isoform cannot be excluded (16).

In terms of isometric knee extensor strength, the weightlifters were on average 32% stronger than the controls with the decline in strength occurring at 0.6% per annum; this was approximately half the rate observed for muscle power. Skelton et al. (13) reported that average power declined at 3.5% per annum between 65 and 85 yr (of a 77-yr-old's value) but that isometric strength declined at a lower rate (~1.5% per annum). In that study, power was determined using a single inertial load. As already alluded to, it is possible that this puts the weaker older people at a disadvantage as they are unable to sufficiently accelerate a heavy flywheel to obtain a velocity to allow them to generate their optimal power. In the present study, we have optimized the inertial load for power generation, yet the rate of decline in power was still greater than that of isometric strength, suggesting that in addition to declines in strength, alterations in shortening speed may play also a role. In this regard, although the decline in TQ_{mpp} was more dramatic (Fig. 5), there was also an age related slowing of the V_{mpp} . Recent mechanical studies on human chemically skinned single fibers (9) and using the *in vitro* motility assay (7) suggest that their may be intrinsic changes with age that may slow cross-bridge cycling.

The results of the sEMG support the notion that the weightlifters can activate their muscles during an isometric contraction with a more synchronous firing pattern as indicated by the RMS data. In fact, the RMS, which can be used as a measure of general muscle activation, was significantly higher in the weightlifters in all age groups. It has been suggested by Stulen and DeLuca (14) that the MDF of the power spectrum for the sEMG is related to muscle fiber composition. The higher values of MDF for the weightlifters from the power spectrum analysis (Fig. 7a), might suggest a higher proportion of Type II fibers in the weightlifters.

It was hypothesized that weightlifters may produce less antagonist co-contraction than the controls during isometric knee extension. However, similar levels of co-contraction are seen between the two groups (Figure 7c). This may, in part, be due to the fact that a number of weightlifters described having some knee discomfort during the test and it was possible that the weightlifters utilized the antagonist

muscles to help protect the knee during these isometric contractions.

In conclusion, the results of the present cross-sectional study have shown that the apparent decline in lower-limb muscle function occurs even in highly trained weightlifting athletes and that the relative rate of decline is similar to that which occurs as a result of normal aging. For each individual, the optimization of inertial load for power testing was shown to be important as the weightlifters developed their maximal power at a higher inertial load than the untrained control subjects. In functional terms, however, it is the ability to generate absolute levels of force and power that determine the ability of older people to perform physical tasks. When looked at in absolute terms, the data in the present study show that weightlifters are considerably stronger and more powerful, with the oldest weightlifters having muscle power characteristics of individuals some 20 yr younger than themselves. These results therefore suggest that high-resistance strength training for older people might

not slow the rate of decline in muscle function with increasing age but may result in a shift upward to a new slope that starts at a higher absolute level but that has a similar relative rate of decline. The data presented here suggest that activities which require repetitive high levels of muscle power to be generated as in weightlifting may help improve or maintain muscle function in later life

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