Influence of Age on Isometric, Isotonic, and Isokinetic Force Production Characteristics in Men

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ABSTRACT

Background and Purpose: Most previous studies have focused on the effects of age on muscle performance of a single type of contraction, usually isometric, and usually on only a single muscle group. Instead, we investigated the influence of age on isometric, isotonic, and isokinetic muscle performance in men aged 20-83 years and determined relationships between regional lean body mass and muscle performance. **Methods**: Seventy-five volunteers were placed into designated 10-year age groups: 20–29 (n=13), 30–39 (n=14), 40–49 (n=15), 50–59 (n=10), 60–69 (n=14), and 70+ years (n=9). Muscle performance was characterized by a number of parameters, including strength, time, and rate for maximal voluntary contractions using all 3 contraction types and 4 muscle groups (elbow extensors, elbow flexors, knee extensors, and knee flexors). Measures of lean body mass were obtained by dual energy x-ray absorptiometry. **Results:** There were significant age group differences in maximal force ($P < 0.05$) for each type of muscle contraction, and in maximal rates of isometric force production ($P < 0.05$), with declines beginning around 60 years of age. Differences in muscle performance between age groups remained when body composition differences were controlled statistically. **Conclusion:** Chronological age affected performance of both upper and lower extremity muscles, independent of muscle mass, and regardless of contraction type; however, isometric performance was the least affected.

Key Words: muscle performance, age, body composition, measurement

INTRODUCTION

Early studies addressing the association of muscle performance with age often focused on strength, particularly isometric hand grip force.[1-4] With the advancement of technology, the assessment of other muscle actions and performance parameters (eg, the time required to reach maximal force, the rate at which force can be produced) has followed. Still, few isokinetic strength studies involving the upper extremities[5] have been published, especially studies focusing on age-related differences in isokinetic strength.

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The reduction of muscle strength and muscle mass demonstrated by the elderly has been attributed to aging itself and to lower levels of trophic physical activity. Muscle strength tends to peak between 20 and 30 years of age followed by a gradual decline. Healthy men and women in their seventh and eighth decades typically average about 20% to 40% less strength than young adults,[6-8] while the very old demonstrate an accelerated decrease in muscle strength.[4,9] This loss of strength may have a marked effect on the capacity of elderly men and women to lead independent lives. Therefore, the purpose of this study was to investigate the influence of chronological age on isometric, isotonic, and isokinetic muscle performance in men aged 20 to 83 years. A secondary objective was to determine relationships between regional lean body mass and the performance characteristics examined.

METHODS

This study was approved by the Institutional Review Board of the University of Oklahoma, and as such, written informed consent was obtained from each subject prior to testing. In addition, medical clearance and information regarding past and present health status and physical activity levels was obtained using 4 surveys: Physical Activity Readiness Questionnaire (PAR-Q),[10] Godin Leisure-Time Exercise questionnaire,[11] Lipid Research Clinics Physical Activity questionnaire,[12] and a Pre-Participation questionnaire designed specifically for this study.

The PAR-Q[10] was used to confirm the safety of testing individuals 60 or more years of age who had already been cleared medically. Specifically, their participation was dependent on their answering "No" to each of the 7 questions of the PAR-Q. The Godin Leisure-Time Exercise questionnaire[11] was employed to determine how many times during a typical 7-day period that subjects performed either strenuous, moderate, or mild exercise for more than 15 minutes during free times or how often they worked up a sweat. The Lipid Research Clinics Physical Activity questionnaire[12] asked participants to compare themselves to others of their own age and gender relative to the activities they do at work and during leisure time. The Pre-Participation questionnaire also asked about any significant injuries or limitations that might limit the ability to obtain a maximal effort for each muscle group and each contraction type and to make sure that subjects were not engaged in resistance training during the previous 12 months. Those with limitations or who had weight trained were excluded from the study.

Subjects

Seventy-five normal, healthy males between the ages of 20 and 83 years were distributed into 6 distinct 10-year agespan categories as follows: 20–29 (n=13), 30–39 (n=14), 40–49 (n=15), 50–59 (n=10), 60– 69 (n=14), and 70 + years (n=9). All subjects were recruited from the local and surrounding communities and were selected on the criterion that they had not engaged in a habitual weight-training program during the previous year.

Research Design

Each subject participated in 2 separate testing sessions. During the first session, anthropometric measures and body composition data were obtained from dual energy x-ray absorptiometry (DXA). Isokinetic, isometric, and isotonic strength tests were performed during session 2 for each of the 4 muscle groups (elbow extensors and flexors and knee extensors and flexors). The within-day (trial) and between day reliability of the muscle performance measurements were initially established on a subsample of 11 subjects with an age range of 20 to 44 years. These subjects had each of the 4 muscle groups and 3 contraction types assessed on 2 separate days while the order of testing was kept constant during both days of testing: (1) isokinetic, (2) isometric, (3) isotonic.

Isokinetic Protocols

Prior to the strength assessment, each subject performed a 5-minute warm-up on a stationary bicycle followed by a 5-minute static stretching routine.[13] A Biodex® isokinetic dynamometer (Shirley, NY) was calibrated daily and the testing order of the elbow (extensors and flexors) and knee (extensors and flexors) was simply alternated with subsequent participants. Once seated, the subjects were secured with lap and shoulder restraints, and testing was performed at each testing speed (60°/sec, 180°/sec, and 240°/sec) for the selected muscle groups.

To test the musculature of the right lower extremity (knee extension and flexion), the right thigh was stabilized with a Velcro strap, the dynamometer was aligned with the anatomical axis of the knee, and the right lower leg was secured against the shin pad just proximal to the medial malleolus. Subjects were then allowed to perform an initial warm-up of 5 to 10 submaximal repetitions at 60°/sec, through a range of 0° to approximately 120° of knee flexion. Following a 1-minute rest period, subjects were instructed to exert force as hard and as fast as possible by continuously alternating concentric contractions of the knee extensors and flexors at 60°/sec for 3 consecutive trials. Following a 1-minute rest period, this process was repeated at 180°/sec and 240°/sec.

To test the muscle groups of the right upper extremity (elbow extension and flexion), the subject was seated with the right shoulder flexed approximately 60°, and the elbow stabilized with a Velcro strap after aligning the dynamometer with the anatomical axis of the elbow. The forearm was allowed to remain in a neutral position. The warm-up, instructions, rest periods, and testing speeds were the same for both upper and lower extremity testing.

Isometric Protocols

The Isometric Strength Assessment Cage (ISAC), described previously by Bemben et al, was used to measure isometric muscle performance.[14] The apparatus was built around an adjustable chair that had been fitted with Simpson Racing Straps® in order to maximize body stabilization. Lockable and moveable stabilization bars had attachment points for the load cells. Each load cell was linked to a computer system that utilized a Lab Tech for Windows program (v. 1996) to convert the digital reading of the load cell into numerical expressions of force (kg) at the rate of 100 data points per second. Calibration of this apparatus was performed prior to testing each muscle group and the testing order was held constant for all subjects as follows: elbow extensors, elbow flexors, knee flexors, and knee extensors. The subjects were specifically instructed to perform each of the required movements "as fast and as hard as possible during a single continuous effort." Subjects were allowed several submaximal efforts to become familiar with the task, then 3 maximal trials were performed for each muscle group with a 1-minute rest period between trials.

Elbow extension force was measured with the subject seated in an upright position and secured with the upper arm vertical, the elbow flexed at 90° (measured goniometrically), and the forearm in neutral position. An adjustable 1.5-inch nylon strap, lined with a padded cloth for comfort, encircled the distal forearm at the styloid process of the ulna. The nylon strap was secured vertically from an overhead stabilization bar, with a load cell in series. The subject generated force by extending the elbow and exerting force against the strap, which had no give when set.

Elbow flexion force was measured with the subject in same position as the elbow extension task. Elbow flexion was measured goniometrically and placed at 90°. The nylon strap and load cell were secured directly below the styloid process of the radius in the vertical plane. Elbow flexion force was measured with the subject exerting force by flexing the elbow, resulting in an upward force against the load cell.

Knee flexion force and knee extension force were both measured with the subject in the identical seated position. The knee was goniometrically measured and placed at 90° of knee flexion for both tests. The nylon strap and load cell apparatus was placed approximate to the horizontal plane, perpendicular to the lower leg, for both tests, and secured in front and behind the leg for the knee flexion and knee extension tests, respectively.

Isotonic Protocols

Isotonic muscle strength was assessed by a 1 repetition maximum (1-RM) test for each exercise using CYBEX® isotonic resistance machines (Ronkonkoma, NY). Prior to testing, each subject was instructed on proper lifting technique, fitted for each machine, and then performed a specific warm-up for each muscle group using standard submaximal loads that could be easily lifted. During the 1-RM testing, subjects rested for 1 minute between each attempt with no more than 5 attempts being made. Testing order was the same as isometric testing.

Body Composition

Estimations of total body and regional body composition were obtained using dual energy x-ray absorptiometry (DXA)

(Lunar DPX-IQ, software version 4.6b). As an individual's muscle performance is affected by muscle mass, regional and total body lean body mass measures were obtained from subjects in order to control statistically for these differences. Both lean body mass (LBM) and bone-free LBM were determined from the total body DXA scans for the right upper and lower extremities and for the total body. The DXA was calibrated each testing day by using the quality assurance procedures and to minimize variability between scanning subjects, consistent body positioning, use of anatomical landmarks, and scan speeds were recorded for each subject. Scan speeds were determined by the estimated thickness of the subject's trunk region. Analyses of all the DXA scans were performed by the same technician.

Muscle Performance Variables

The dependent variables of peak torque (PT) in Nm, time to PT (sec), and angle of PT (deg) were determined from isokinetic testing. After careful visual analysis of the torque production curves, PT was selected from the highest torque value obtained from the 3 trials, the curve was smoothed to reduce the influence of random fluctuations, and the angle and time to PT were determined. Isometric muscle performance measures included: maximal force (MF) in kg, time to MF (sec), and the maximal rate of force production (kg/sec). MF is equivalent to the term strength and is the highest point on the force-time curve for a given contraction. Time to MF is the amount of time elapsed on a force-time curve from a point corresponding to 10% of MF to the point that MF is achieved, and the maximal rate of force production was defined as the greatest increase in force over any 60ms time period during a maximal isometric contraction. Three isometric trials were completed for each muscle and if there were no statistical differences between the 3 trials, an average of the 3 readings was used for further analyses. The 1-RM was used to represent isotonic strength. The 1-RM was expressed to the nearest kg.

Data Analyses

Statistical analyses were performed using SPSS for windows (version 11.0). Descriptive statistics were performed for all dependent variables to describe each age group's physical characteristics and the muscle performance capabilities of the subjects. To assess the reliability of muscle performance data, two-way repeated measures (trial x day) analysis of variance (ANOVA) and intraclass correlation coefficients (ICCs) were used. Differences between age groups with respect to body composition and muscle performance were assessed by one-way ANOVA. When age group differences were detected, trend analyses were used as a post-hoc test. Pearson correlation coefficients (r) were used to determine relationships between body composition variables and muscle performance and analyses of covariance (ANCOVA) were employed to statistically control for any age related contribution of lean tissue to differences in muscle performance. Statistical significance for this study was set at $P \leq 0.05$.

RESULTS

Questionnaire Data

In general, each age group averaged about 1 day per week in strenuous activity, about 2 days per week in moderate activities, and between 2 and 3 1/2 days per week in mild activities. Only the mild activity category for the young group (about 3 1/2 days per week) appeared to be different than the other age groups (between 2 and 3 days per week). Additionally, individuals of the groups felt as though they were more active than others of their own age and gender.

Table 1. Descriptive Measures of Each Age Group

Age Group (years)	n	Age (years)	Standing Height (cm)	Body Weight (kg)	Total Body Fat (%)	Total Body Fat (kg)
20-29	13	22.9 (0.8)	180.7 (2.1)	88.8 (5.4)	23.4 (1.6)	21.3 (2.6)
30-39	14	34.5 (0.8)	178.1 (1.7)	87.8 (3.8)	24.9 (1.8)	22.3 (2.3)
40-49	15	45.3 (0.8)	179.8 (1.9)	90.9 (4.2)	25.4 (1.5)	23.3 (1.9)
50-59	10	53.0 (0.7)	177.0 (1.6)	99.5 (7.1)	27.7 (1.9)	27.8 (3.0)
60-69	14	63.6 (0.7)	177.6 (2.5)	85.4 (5.3)	25.3 (1.2)	21.4 (1.7)
70 +	9	74.3 (1.2)	174.4 (1.9)	77.2 (3.2)	25.9 (1.7)	19.7 (1.6)

Values are mean (standard error)

Table 2. Total and Regional Lean Body Mass (LBM) for each Age Group

Age Group (yrs)	n	Total Body LBM (kg)	Total Body Bone-Free LBM (kg)	Right Upper Extremity LBM (kg)	Right Upper Extremity Bone-Free LBM (kg)	Right Lower Extremity LBM (kg)	Right Lower Extremity Bone-Free LMB (kg)
20-29	13	66.3 (2.9)	62.7 (2.8)	4.0 (0.2)	3.7 (0.2)	11.2 (0.5)	10.5 (0.5)
30-39	12	65.6 (2.8)	62.1 (2.7)	4.0 (0.2)	3.8 (0.2)	11.0 (0.5)	10.3 (0.4)
40-49	15	66.7 (2.6)	63.0 (2.6)	4.0 (0.2)	3.8 (0.2)	10.9 (0.4)	10.2 (0.4)
50-59	10	69.6 (3.5)	66.2 (3.4)	4.0 (0.2)	3.8 (0.1)	11.3 (0.6)	10.6 (0.6)
60-69	14	62.5 (3.4)	59.3 (3.2)	3.6 (0.1) †	3.4 (0.1) †	10.1 (0.5)	9.5 (0.5)
70 +	9	56.1 (2.6)	53.0 (2.5)	3.1 (0.2)	2.9 (0.2)	9.2 (0.4)	8.6 (0.4)

Values are mean (standard error)
Note: † indicates critical age group where differences occurred (significant quadratic trend)

Physical Characteristics

The mean and standard error for age (years), standing height (cm), body weight (kg), total body percent fat (%), and total body fat mass (kg) are given for each age group in Table 1. The mean age for most groups demonstrated a good distribution of individuals within each group, and indicates a good representation of each particular group. There were no significant differences ($P > 0.05$) in standing height, body weight, percent fat, or fat mass between the age groups.

The mean and standard error for the lean tissue body composition variables (LBM, bone-free LBM) obtained from DXA are presented in Table 2. No significant group differences ($P > 0.05$) were detected for either of the total body measures (LBM and bone-free LBM); however, significant group decreases were revealed for right upper extremity LBM ($P < 0.01$) and bone-free LBM ($P < 0.01$), with the critical age group being the 60-69 year group. No group differences were found for LBM or bone-free LBM ($P = 0.06$) of the right lower extremity; however, the masses of the older age groups were lower than those of the younger age groups.

Reliability

Based on only a small number of significant findings (10 of 64 analyses) obtained from 2 days of repeated trials for all 3 contraction types and the 4 muscle groups (ANOVA) and high ICCs, we decided that 1 day of testing was adequate. The day to day ICCs were .80 to .99 for isokinetic parameters, .95 to .98 for isotonic parameters, and ranged .78 to .94 for isometric parameters.

Isokinetic Peak Torque

Isokinetic PT declined with increased testing velocity for all age and muscle groups (Tables 3–6). The ANOVAs revealed significant differences ($P < 0.001$) in PT between the age groups and for each muscle group (elbow extensors and flexors, and knee extensors and flexors) at each of the 3 veloc-

Table 3. Peak Torque (PT), Angle of PT, and Time to PT from Isokinetic Testing of the Elbow Extensors at Different Speeds for each Age Group

Variable	**20-29 yrs** (n=13)	**30-39 yrs** (n=14)	**40-49 yrs** (n=15)	**50-59 yrs** (n=10)	**60-69 yrs** (n=14)	**70+ yrs** (n=9)
PT (Nm)						
60°/sec	69.9 (4.4)	67.1 (4.2)	70.8 (4.3)	65.0 (3.3)	49.6 (3.6)†	42.0 (4.5)
180°/sec	59.2 (3.2)	60.2 (3.3)	61.5 (3.3)	58.2 (2.9)	46.7 (3.4)†	40.6 (2.9)
240°/sec	55.3 (3.3)	58.4 (2.9)	58.3 (3.4)	57.2 (3.0)	45.3 (3.2)†	39.3 (2.3)
Angle of PT (deg)						
60°/sec	64.5 (2.0)	68.8 (5.5)	63.7 (4.4)	66.5 (7.3)	69.9 (4.2)	59.6 (5.5)
180°/sec	44.2 (3.1)	47.6 (5.7)	42.7 (5.8)	42.8 (6.8)	45.6 (7.0)	33.7 (5.9)
240°/sec	41.0 (4.0)	42.7 (8.2)	42.2 (7.6)	40.6 (8.1)	41.5 (7.8)	24.4 (5.0)
Time to PT (sec)						
60°/sec	1.26 (.04)	1.18 (.09)	1.21 (.09)	1.14 (.12)	1.18 (.10)	1.51 (.10)
180°/sec	0.62 (.02)	0.58 (.04)	0.58 (.04)	0.59 (.04)	0.64 (.06)	0.82(.07)†
240°/sec	0.54 (.02)	0.48 (.04)	0.48 (.03)	0.46 (.04)	0.52 (.04)	0.68(.05)†

Values are mean (standard error)
Note: † indicates critical age group where differences occurred (significant quadratic trend)

Table 4. Peak Torque (PT), Angle of PT, and Time to PT from Isokinetic Testing of the Elbow Flexors at Different Speeds for each Age Group

Variable	**20-29 yrs**(n=13)	**30-39 yrs** (n=14)	**40-49 yrs** (n=15)	**50-59 yrs** (n=10)	**60-69 yrs** (n=14)	**70+ yrs** (n=9)
PT (Nm)						
60°/sec	45.8 (2.8)	45.6 (3.3)	47.0 (3.2)	44.4 (3.1)	35.2 (2.0)†	25.4 (2.5)
180°/sec	36.0 (2.2)	38.5 (2.7)	38.5 (2.9)	37.1 (2.9)	26.7 (1.8)†	19.8 (1.9)
240°/sec	31.7 (2.4)	35.2 (2.8)	35.1 (2.9)	34.6 (3.0)	25.5 (1.8)†	16.7 (2.3)
Angle of PT (deg)						
60°/sec	75.2 (2.8)	80.6 (2.3)	74.9 (2.4)	70.8 (2.8)	81.1 (1.9)	80.9 (4.1)
180°/sec	79.5 (3.4)	78.3 (5.2)	72.5 (4.9)	71.3 (6.5)	77.2 (4.5)	85.8 (6.4)
240°/sec	71.3 (4.6)	66.8 (4.4)	65.0 (3.7)	62.0 (4.1)	68.6 (4.7)	71.3 (8.2)
Time to PT (sec)						
60°/sec	1.23 (.05)	1.38 (.04)	1.29 (.06)	1.24 (.05)	1.40 (.07)†	1.66 (.07)
180°/sec	0.54 (.02)	0.52 (.03)	0.50 (.03)	0.50 (.05)	0.51 (.05)	0.71 (.06)†
240°/sec	0.41 (.02)	0.39 (.02)	0.38 (.02)	0.39 (.04)	0.41 (.03)	0.48 (.05)

Values are mean (standard error)
Note: † indicates critical age group where differences occurred (significant quadratic trend)

Table 5. Peak Torque (PT), Angle of PT, and Time to PT from Isokinetic Testing of the Knee Flexors at Different Speeds for each Age Group

Variable	**20-29 yrs**(n=13)	**30-39 yrs** (n=14)	**40-49 yrs** (n=15)	**50-59 yrs** (n=10)	**60-69 yrs** (n=14)	**70+ yrs** (n=9)
PT (Nm)						
60°/sec	90.1 (3.9)	87.3 (6.9)	93.0 (5.9)	77.8 (6.4)†	66.8 (5.7)	45.7 (6.1)
180°/sec	76.9 (2.3)	72.2 (5.3)	69.7 (4.5)	66.0 (4.9)	55.1 (3.8)	43.6 (5.7)
240°/sec	70.7 (3.7)	63.3 (5.1)	61.4 (4.3)	60.3 (5.1)	47.3 (4.0)	40.4 (5.9)
Angle of PT (deg)						
60°/sec	48.6 (3.9)	57.8 (5.4)	48.5 (4.3)	48.5 (4.4)	56.8 (5.2)	69.1 (6.5)
180°/sec	83.1 (1.7)	80.6 (3.6)	79.5 (4.4)	79.3 (4.6)	77.5 (5.3)	86.0 (3.1)
240°/sec	79.8 (6.1)	79.1 (6.3)	69.8 (6.2)	82.5 (6.0)	69.8 (5.3)	87.5 (6.7)
Time to PT (sec)						
60°/sec	0.71 (.06)	0.84 (.09)	0.63 (.07)	0.64 (.07)	0.81 (.09)	1.12 (.11)†
180°/sec	0.47 (.02)	0.48 (.02)	0.43 (.03)	0.46 (.03)	0.47 (.04)	0.58 (.02)†
240°/sec	0.35 (.03)	0.37 (.03)	0.30 (.03)	0.39 (.03)	0.37 (.03)	0.49 (.04)

Values are mean (standard error)
Note: † indicates critical age group where differences occurred (significant quadratic trend)

Table 6. Peak Torque (PT), Angle of PT, and Time to PT from Isokinetic Testing of the Knee Extensors at Different Speeds for each Age Group

Variable	**20-29 yrs**(n=13)	**30-39 yrs** (n=14)	**40-49 yrs** (n=15)	**50-59 yrs** (n=10)	**60-69 yrs** (n=14)	**70+ yrs** (n=9)
PT (Nm)						
60°/sec	227.9 (13.5)	195.2 (13.7)	188.1 (13.8)	169.7 (12.1)	139.5 (9.0)	88.3 (10.1)
180°/sec	157.3 (7.6)	145.2 (9.7)	137.2 (8.9)	123.0 (6.4)	101.4 (6.2)†	68.8 (6.0)
240°/sec	139.4 (7.0)	131.2 (8.4)	118.7 (7.5)	111.9 (6.1)	89.6 (5.2)	62.9 (4.1)
Angle of PT (deg)						
60°/sec	64.8 (1.5)	69.9 (2.0)	69.1 (3.1)	66.0 (3.9)	64.6 (3.2)	57.9 (6.5)
180°/sec	50.6 (3.2)	58.6 (2.6)	64.9 (2.6)	58.0 (5.5)	57.5 (4.7)	37.2 (4.7)†
240°/sec	55.3 (3.5)	57.0 (4.0)	57.3 (4.2)	50.4 (6.7)	59.5 (3.8)	48.3 (6.9)
Time to PT (sec)						
60°/sec	0.90 (.03)	0.84 (.05)	0.87 (.05)	0.90 (.06)	0.91 (.05)	1.01 (.12)
180°/sec	0.40 (.02)	0.36 (.02)	0.34 (.02)	0.36 (.04)	0.38 (.02)	0.64 (.08)†
240°/sec	0.32 (.02)	0.29 (.02)	0.31 (.02)	0.32 (.03)	0.30 (.02)	0.39 (.04)

Values are mean (standard error)
Note: † indicates critical age group where differences occurred (significant quadratic trend)

ities. PT of the elbow extensors had both significant linear ($P < 0.01$) and quadratic trends ($P < 0.05$) across age groups for each testing velocity. Men aged 20-59 years had stronger elbow extensors than the men aged 60-83 years. PT of the elbow flexors also had both significant linear ($P < 0.01$) and quadratic trends ($P < 0.01$) across age groups at each of the velocities. Again, men aged 20-59 years had stronger elbow flexors than the older men. PT of the knee flexors had both significant linear ($P < 0.01$) and quadratic trends ($P < 0.01$) at 60°/sec, but only a significant linear trend ($P < 0.01$) at 180°/sec and 240°/sec. At 60°/sec, men aged 20-49 years produced greater knee flexor PT than men age 50-83 years. Knee flexor PT declined linearly after age 29 years when tested at 180°/sec and 240°/sec. PT of the knee extensors had both significant linear ($P < 0.01$) and quadratic trends ($P < 0.05$) at 180°/sec, but only a significant linear trend ($P < 0.01$) at 60°/sec and 240°/sec. At 180°/sec, men aged 20-59 years produced greater knee extensor PT values than men age 60-83 years. Knee extensor PT declined linearly after age 29 years when tested at 60°/sec and 240°/sec.

Angle of Isokinetic Peak Torque

Significant differences between age groups for angle of PT were found only for the elbow flexors at 60°/sec ($P < 0.05$) and for the knee extensors at 180°/sec. No muscle group demonstrated significant differences between age groups for the angle of PT at 240°/sec. Although no discernable pattern over the 6 age groups was found for any of the muscle groups, in general, the oldest group (70+ years) achieved PT later in the range of motion compared to all other age groups. This was true for all muscle groups and all test velocities (Tables 3–6).

Time to Isokinetic Peak Torque

Significant differences in time to PT between age groups were found for the elbow extensors ($P < 0.05$) at 180°/sec and

240°/sec; the elbow flexors ($P < 0.05$) at 60°/sec and 180°/sec; the knee flexors ($P < 0.05$) at 60°/sec, 180°/sec, and 240°/sec; and the knee extensors ($P < 0.001$) at 180°/sec. No definitive pattern could be identified over the 6 age groups for any muscle group except that the slowest time to PT occurred in the oldest age group (70+ years) for each muscle group at each testing velocity (Tables 3–6).

Isometric Maximal Force

The ANOVA revealed significant differences in MF between age groups for the elbow extensors ($P < 0.001$), elbow flexors ($P < 0.005$), and knee extensors ($P < 0.001$), but not the knee flexors ($P > 0.05$) (Figure 1). For the elbow flexors and extensors and knee extensors, trend analyses indicated that MF measures had both significant linear ($P < .01$) and quadratic ($P <.05$) trends. The MF for the elbow extensors was greater for subjects 20-59 years (mean = 28.2 kg) than for subjects of 60 or more years (mean = 20.7 kg). For the elbow flexors, MF was greater for subjects 30-59 years (mean= 35.2kg) than for subjects 20-29 years (mean = 31.8 kg); however, the MF was less for subjects of 60–69 years (mean =29.3 kg) and 70 plus years (mean = 23.7 kg). MF of the knee extensors was greatest for subjects 20–59 years (mean =56.8 kg), followed by subjects 60–69 years (mean = 44.7 kg), and then by subjects 70 plus years (mean = 31.9 kg). Although trend analysis did not reveal a statistically significant difference between age groups in the MF of the knee flexors, there was a pattern similar to that of the knee extensors (ie, strength was maintained through age 59 years before declining).

Time to Isometric Maximal Force

For time to MF, ANOVA results indicated that significant differences existed between age groups for the elbow flexors ($P < 0.005$), but not for the elbow extensors or the knee flexors and extensors ($P > 0.05$). Trend analysis indicated that the elbow flexors had a significant ($P < 0.01$) linear increase in time to MF as age increased. Although there were no statistically significant differences in time to MF between the age groups for the elbow extensors, knee flexors, and knee extensors, there was a general linear pattern; the youngest age group produced the fastest times for each muscle group and the older age groups produced slower times (Figure 2).

Maximal Rate of Isometric Force Production

Significant differences existed for maximal rate of force production between age groups for each muscle group (elbow extensors, $P < 0.001$; elbow flexors, $P < 0.005$; knee flexors, $P < 0.05$; and knee extensors, $P < 0.005$). Maximal rates for the elbow extensors increased from a mean 202.7 kg/sec (20–29 years) to 228.2 kg/sec (30–39 years), before declining

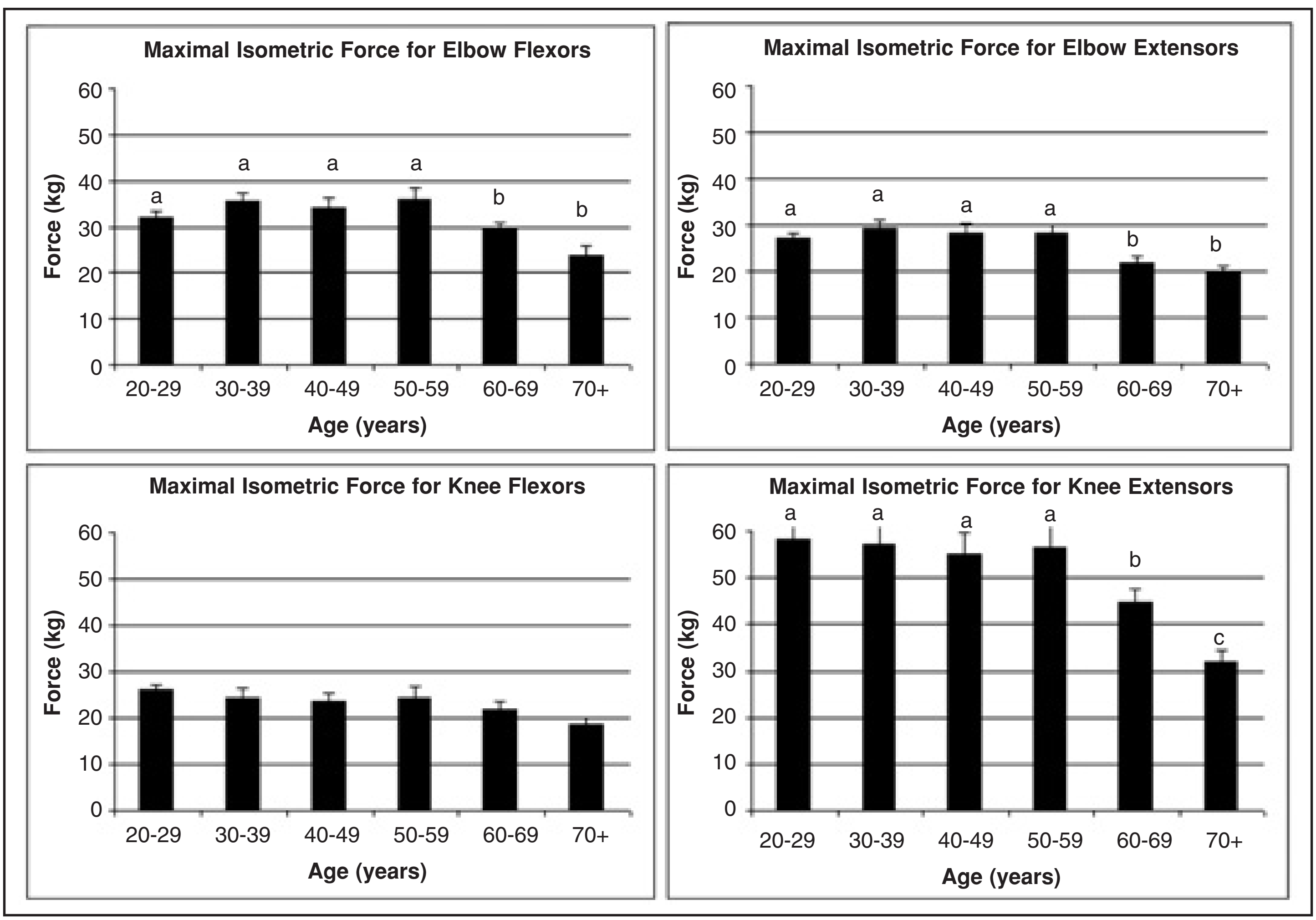

Figure 1. MF (Mean ± SE) obtained from maximal voluntary isometric contractions. a, b, c denote significant differences between groups (P < 0.05).

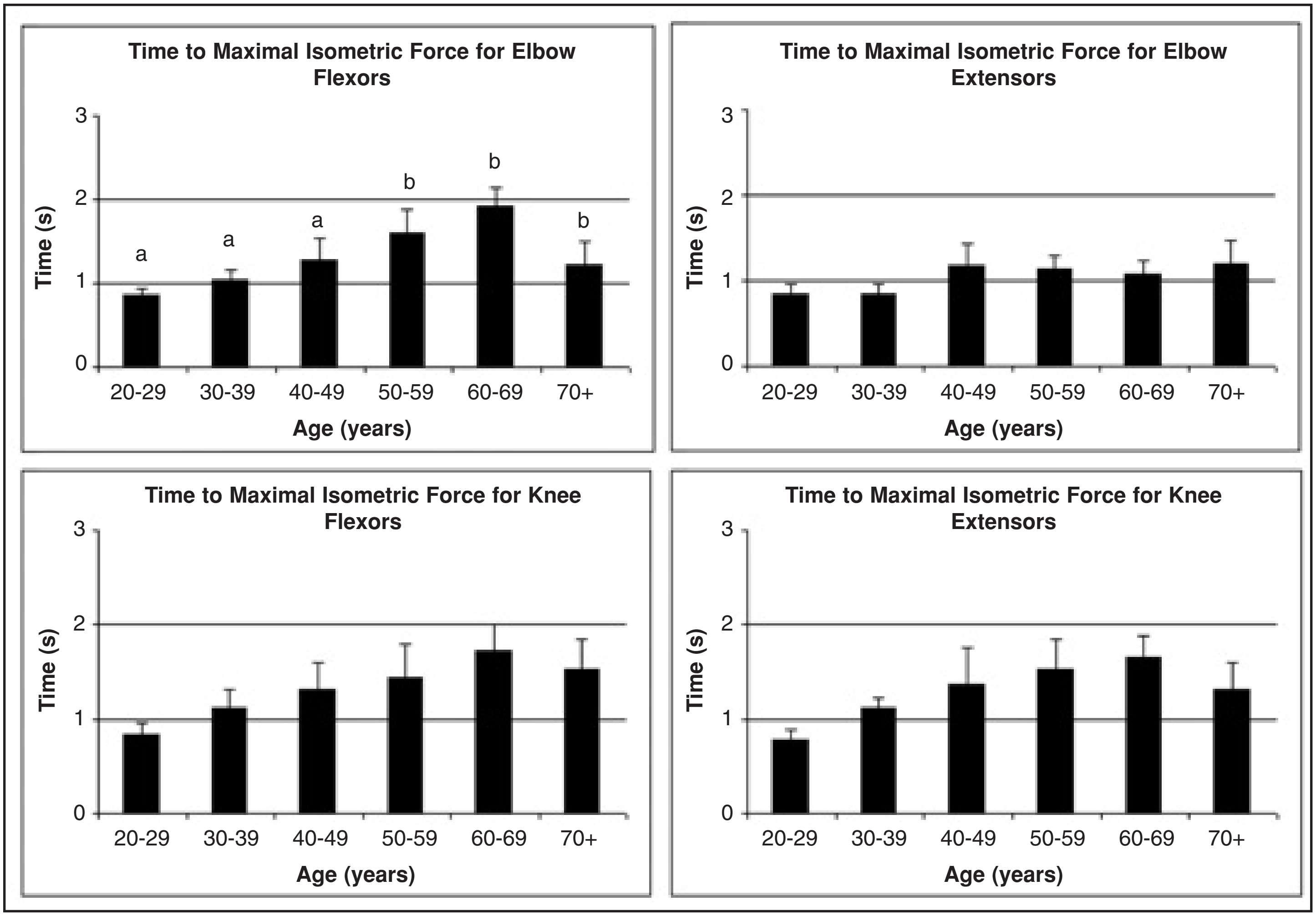

Figure 2. Time to MF (Mean ± SE) obtained from maximal voluntary isometric contractions. a, b denote significant differences between groups (*P* < 0.05).

steadily to 90.4kg/sec for the 70 plus age group. Maximal rates for the elbow flexors gradually increased from 20–29 years (mean=193.7 kg/sec) to 40–49 years (mean=269.0 kg/sec) before demonstrating a sharp steady decline through age 70 plus years (mean =109.5 kg/sec). For the knee flexors, maximal rates demonstrated a general linear pattern, declining with increasing age. For the knee extensor muscles, the 4 youngest age groups showed a greater rate of force production than the older groups (Figure 3).

One-Repetition Maximum Isotonic Strength

The 1-RM measures for each muscle group differed significantly ($P < .05$- $P < .001$) between age groups (Figure 4). Significant linear ($P < 0.01$) and quadratic ($P < 0.05$) trends were demonstrated for the 1-RM across ages. The 1-RM values from the elbow flexors, knee flexors, and knee extensors were greatest for subjects 20–59 years, followed by subjects 60–69 years, and then subjects 70–83 years. For the elbow extensors, 1-RM values were similar for subjects 20–69 years), but significantly less for subjects of 70 plus years.

Relationship of Force Production and Body Composition

The correlation coefficients between body composition (total and regional measures of LBM) and muscle performance variables were highly significant ($P \leq .01$), but only moderate in strength (r = 0.50-0.80). Finally, differences in muscle performance that accompanied aging persisted when the effects of body composition were controlled (ANCOVA).

DISCUSSION

Declines in muscle performance are inevitable during the aging process. However, it is unclear if changes in performance are similar for different muscle groups, if declines are consistent with different types of contractions, or if there is a particular age when changes become more pronounced. Researchers have reported previously that muscle performance declines more rapidly in the lower extremities than in the upper extremities.[15,16] This finding was supported by the present study, however, only when muscle performance was assessed by isokinetic testing. Isokinetic performance of the lower extremity muscles exhibited a linear decline in performance, beginning as early as the 30-39 year age group and accelerating after age 59 years, while the upper extremity muscle performance remained relatively constant from 20-59 years of age before declining with increasing age at all angular velocities.

This effect of extremity on the loss of muscle performance was not apparent for the isometric or isotonic assessments, since, both upper and lower extremity muscle groups

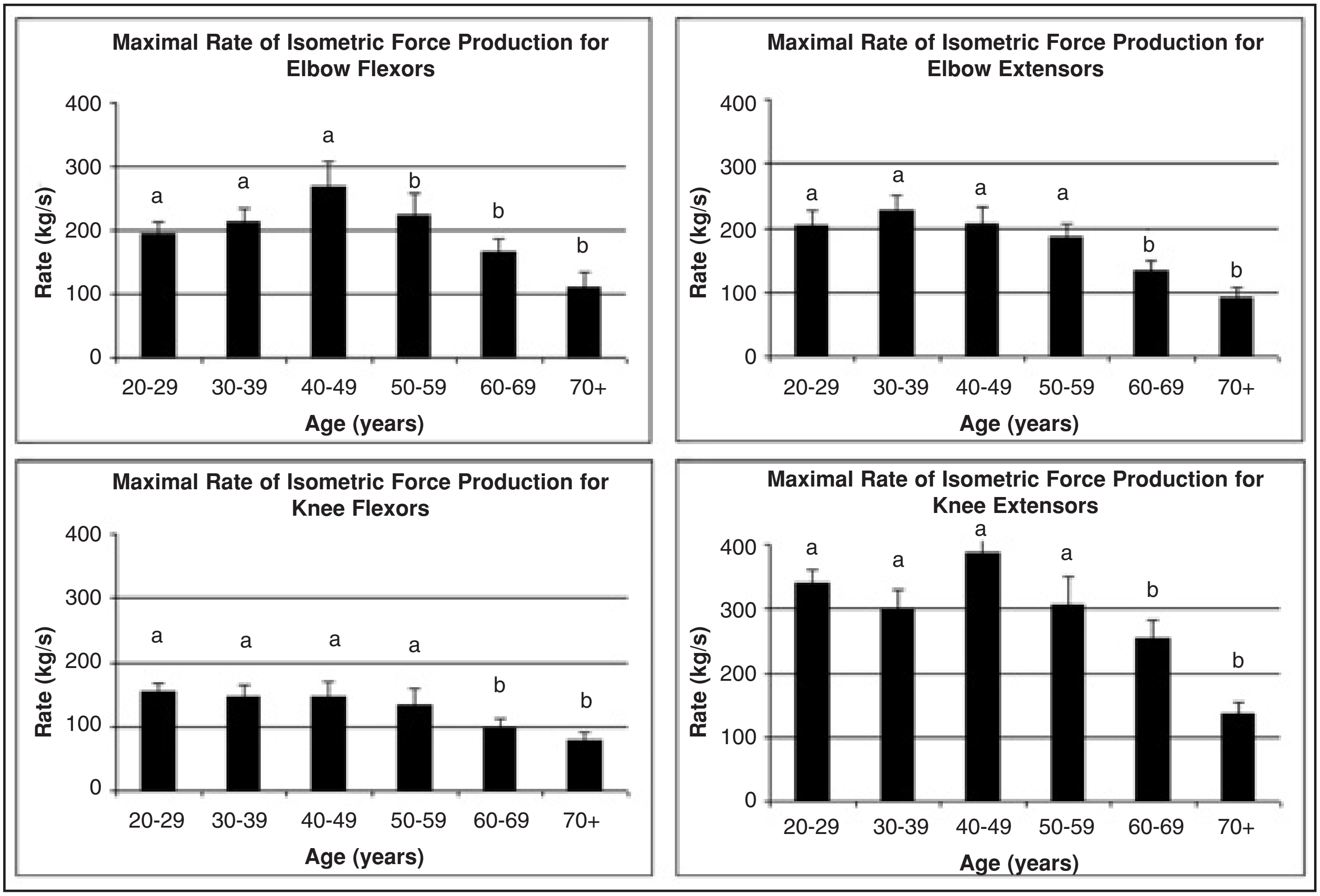

Figure 3. Maximal rate of force production (Mean ± SE) obtained from maximal voluntary isometric contractions. a, b denote significant differences between groups ($P < 0.05$**).**

demonstrated a similar pattern of decline which began with the 60-69 year old age group. In general, the declines in muscle performance, regardless of muscle group or contraction type, seemed to be most obvious at age 60 years where the rate of decline was the greatest (Tables 5-6).

As noted earlier, many studies have assessed isokinetic muscle performance measures in the lower extremities, especially the knee extensor group. The PT values and declines in muscle performance for both the knee extensors and flexors in the current study are similar to previously reported measures.[6,8,13,15,24-27] On the other hand, only a few published studies examined isokinetic muscle performance for the upper extremities. In this study, PT decreased for both the elbow flexors and extensors with increased angular velocity for all age groups. The oldest age group (70+ years) demonstrated 45%, 45%, and 47% less elbow flexion strength at 60°/sec, 180°/sec, and 240°/sec, respectively, when compared to the youngest group (20–29 years) and the percent loss of isokinetic elbow extension PT between the oldest and youngest groups was 40%, 31%, and 29% at the 3 testing speeds, respectively. In a study comparing the isokinetic PT of the upper extremity between young (mean =25.6 years) and old men (mean =54.0 years), Gallagher et al reported a mean 51% less PT in elbow flexion and 12% less PT in elbow extension for the older men; however, it is difficult to make direct comparisons between studies due to methodological differences.[23]

As expected, PT decreased for all age groups as the speed of contraction increased, regardless of the muscle group being examined. When comparing the relative decline in PT with increasing angular velocity (60°/sec vs. 240°/sec), the youngest age group (20-29 years) actually demonstrated a greater decrease in PT at the faster speed compared to the oldest group (70+ years). These results compare favorably with the results presented by Harridge and White,[28] but they differ from other studies in which greater torque decrements were noted for the older age groups at faster isokinetic speeds. However, these studies only tested the knee flexors and extensors at 0°/sec (isometrically) and 120°/sec.[13,24]

Regarding other measures of muscle performance, there is a paucity of information dealing with the influence of age on the time required to reach PT, as well as the angle at which PT occurs. Murray et al reported that the joint position at which PT occurs is related to the speed of the contraction.[8] This can be seen in the results of the current study, with PT occurring later in the range of motion as the speed of contraction increased, regardless of age group (Tables 3-6). These findings are similar to those presented by Stanley and Taylor.[26] This phenomena is also reflected by the slower times to PT evidenced by the oldest age group (70+ years) for all muscle groups and during each testing velocity.

The age related changes that occurred in isometric muscle performance can be compared to previous studies by

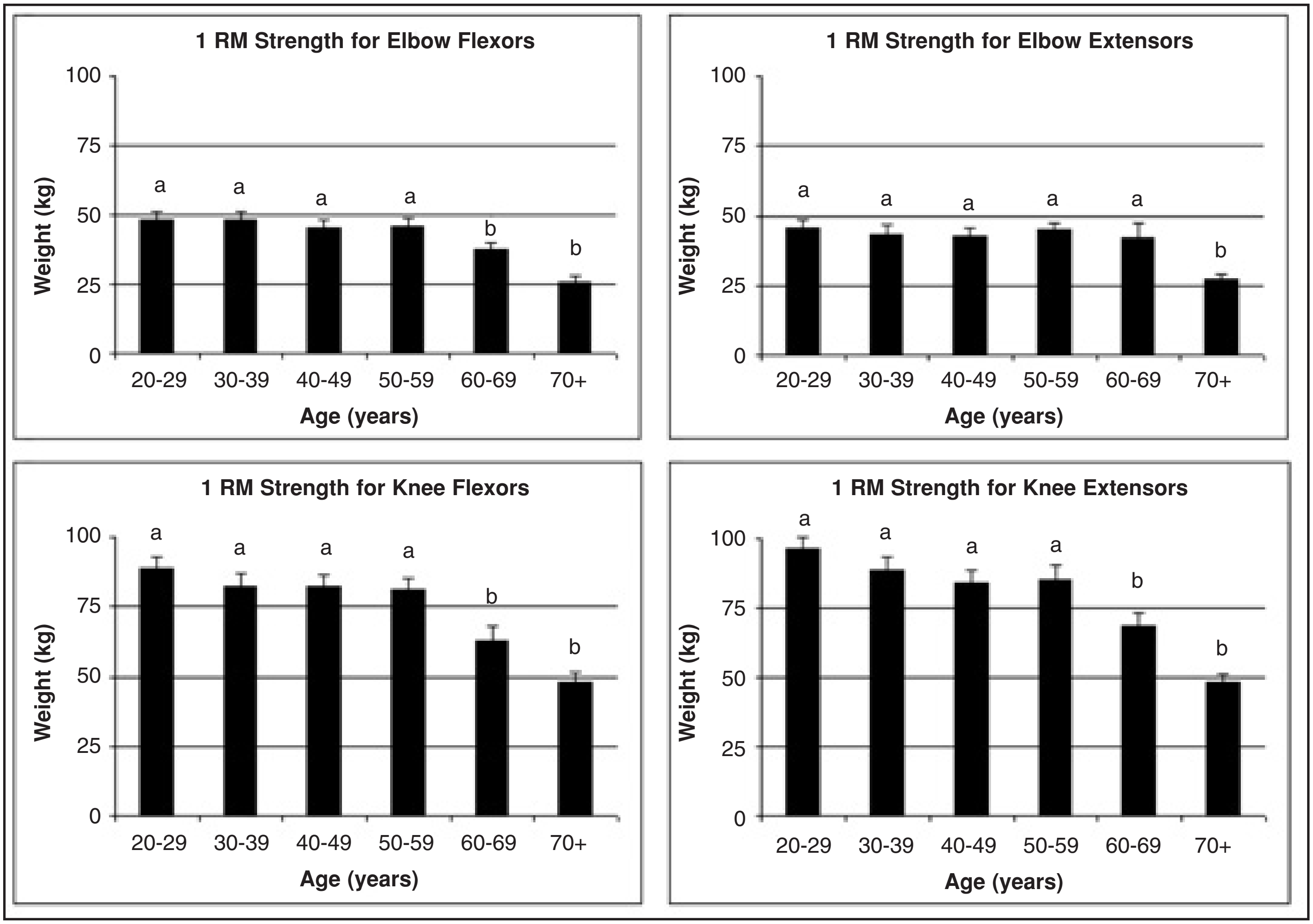

Figure 4. 1-RM (Mean ± SE) obtained from isotonic contractions. a, b denote significant differences between groups ($P < 0.05$).

examining the percent decline in MF between the older and younger age groups. In the current study, the reduction in MF produced by the oldest age group (70+ years) compared to the youngest group (20-29 years) was as follows: elbow flexors = 25%; elbow extensors = 27%; knee extensors = 45%; knee flexors = 29%; and the results are similar to previous findings.[7,8,13,16,22,29-31]

The actual age threshold in which muscle performance begins to decline is not clear within the literature. The obvious age of decline seems to be dependent upon the specific muscle being observed, and to some extent, the physical activity status of the individual. In our study, elbow flexion performance remained constant until beginning to decline after 59 years of age. A similar pattern of maintenance followed by steady decline in elbow flexion strength after age 59 was observed from data presented by Bohannon.[29] This same age threshold of performance decrement was also observed for the elbow extensors, however, other studies have reported a significant decline in elbow extension strength beginning at a much earlier age.[22,29]

Isometric strength of the knee extensors and flexors in this study was greatest for the 20-29 year old group, which remained relatively constant until age 60 years when a noticeable decline occurred. Although earlier ages of decline were reported previously,[29,30] many studies fail to address issues like physical activity levels and most cross-sectional studies use large age-spans (ie, 10 years or greater) to group subjects.

Significant differences in the time to MF between age groups were found in the present study, however, only for the elbow flexor group. Although not statistically significant, the other muscle groups demonstrated a general age related increase in the time needed to reach MF and support the earlier findings of Bemben et al.[22]

Similar to the finding that isometric MF, or strength, appears to change significantly past age 60 years, the ability to exert isometric force quickly follows a similar pattern. There was a 45% decline in the maximal rate of force production observed between the men aged 20-59 years and those in the older age groups (60+ years) for the elbow extensors, while the elbow flexors declined 39%, the knee extensors 41%, and the knee flexors 39%. Declines of smaller magnitude have been observed previously for different muscle groups[22] or based on different age group comparisons.[32]

The reduction in isotonic muscle performance, or 1-RM values, between the oldest (70+ years) and youngest (20–29 years) age groups were as follows: elbow flexors = 47%; elbow extensors = 40%; knee extensors = 50%; knee flexors =

46%. These declines are greater than the 19% and 17% age related declines in bench press and leg press values published by Bemben and McCalip; however, those tests involved multiple joint exercises, and the mean age for the oldest group was 61.2 years (the approximate threshold where age group differences appeared in the current study).[18]

The age-associated reduction of muscle mass due to muscle atrophy closely parallels the decline in muscle performance in the elderly.[9,33] Lexell et al analyzed the autopsied vastus lateralis muscle of 43 previously physically healthy men between 15 and 83 years of age and reported a 40% reduction in muscle mass with increasing age.[34] The muscle atrophy began around 25 years of age with an approximate 10% decrease in muscle mass by age 50, followed by an accelerated reduction thereafter. Vandervoort reported that numerous studies involving radiological observations have also demonstrated that thigh and leg muscles undergo significant size reductions over time that are consistent in timing and magnitude to the loss of strength.[35] Other changes that can affect muscle performance with increased age are the increased amounts of fat and connective tissue that are present within the cross-sectional area of muscle.[13]

The analysis of the body composition data from this study indicates that decreased muscle performance with increasing age is related to more than just the loss of LBM since LBM remained fairly constant with increasing age even though the ability to maintain muscle performance declined. Thus, the observed decline in performance may be related to neural aspects of muscle function, such as the ability to coordinate motor unit firing. This idea is supported by the fact that isometric muscle performance was the least affected of the 3 contraction types with increasing age, since isometric contractions potentially allow greater synchronization and recruitment of available motor units. However, Macaluso et al still reported some decline in isometric performance due to increased coactivation of antagonist muscles of older women when compared to young women during a maximal effort.[31] It should be mentioned, however, that the fairly small sample size associated with the present study may have resulted in a reduced variability of body composition values for the different age groups that makes it difficult to test the potential modulating influence of body composition on the relationship between age and muscle performance.

Other changes in aging muscle may specifically affect the ability to generate forces quickly. Vandervoort reported that decreased axonal conduction velocity and motor endplate deterioration, which could slow synaptic transmission, are both associated with aging.[35] In addition, the significant fast twitch (type II) fiber atrophy along with reductions in sarcoplasmic reticulum volume and activity, and diminished actin sliding speed on myosin, that have been found to occur with aging, can also result in slower muscle contractile properties. Short and Nair[36] report that reduction in the area occupied by type II fibers is in agreement with other studies that show a reduced proportion of fast myosin heavy chain isoforms when comparing sedentary old men to young men.[37,38]

Caution should be used in interpreting these results since subjects in this study were volunteers, the older subjects were probably more active and healthier than the normal age-matched population and therefore greater declines in muscle function could be expected within the general population of older persons. And finally, depending on the contraction type used to assess muscle performance (ie, if only isometric testing was used), one might grossly underestimate the extent to which older individuals are limited.

CONCLUSIONS

In summary, significant age group differences existed in the ability to produce MF, as well as the ability to generate maximal rates of force production, with age 60 years appearing as a critical point. During both isometric and isotonic strength testing, all muscle groups demonstrated a similar pattern, relative maintenance of strength between the ages of 20-59 years, followed thereafter by a decline in force production capabilities. During isokinetic PT assessment, the upper extremity muscles also remained relatively constant from 20-59 years of age before declining with increasing age at all angular velocities. The lower extremity muscles however, generally demonstrated a linear decline of MF following the youngest age group (20–29 years) with the rate of reduction increasing after age 59 years. The differences that were observed in force production capabilities between age groups remained when body composition differences were controlled statistically, indicating that changes maybe inherent within the muscles themselves.

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