

Concentric Isokinetic Torque Characteristics of the Calf Muscles of Active Women Aged 20 to 84 Years

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Study Design: Descriptive, comparative, and correlational study of nonimpaired, active women in 3 age groups.

Objectives: We described age-related concentric isokinetic torque of plantar flexion (PF) of active women and examined the proposal that PF torque at slow to rapid velocities would be influenced by age-related slower muscle contractile properties. We also examined the relationship of age to passive and active force characteristics of the calf muscle.

Background: Aging is associated with decreased calf muscle strength, slower muscle contractile properties, and decreased dorsiflexion (DF) range of motion. Clinical methods of measuring these changes in the calf muscles have not been described adequately.

Methods and Measures: 24 younger women (20 to 39 years), 24 middle-aged women (40 to 59 years), and 33 older women (60 to 84 years) performed maximal concentric PF of the right ankle from maximal passive DF at randomly ordered velocities of $30^\circ \cdot s^{-1}$, $60^\circ \cdot s^{-1}$, $120^\circ \cdot s^{-1}$, and $180^\circ \cdot s^{-1}$. The peak and mean torques and "angular delay" ($^\circ$) from the onset of movement to peak torque were examined using ANOVA. Age was correlated (Pearson product moment r) with the peak and mean torques, "angular delay," velocity at peak torque for $180^\circ \cdot s^{-1}$, and the maximal passive DF angle and torque.

Results: The peak and mean torques decreased with increasing age and velocities. The angular delay at $180^\circ \cdot s^{-1}$ decreased with increasing age. Age was negatively correlated with the peak and mean torques (range, $r = -0.60$ to -0.73), the "angular delay" at all velocities (range, $r = -0.44$ to -0.64), the maximal passive DF angle ($r = -0.73$) and torque ($r = -0.60$), and with the peak torque velocity at $180^\circ \cdot s^{-1}$ ($r = -0.29$).

Conclusions: The results indicate age-related changes for the concentric isokinetic torque of the calf muscles of active women. The angular delay at $180^\circ \cdot s^{-1}$ may show changes influenced by slower muscle contractile properties. Concurrent age-related declines in passive and active calf muscle force characteristics were demonstrated. *J Orthop Sports Phys Ther* 1999;29:181-190.

Key Words: age, elderly, strength

The calf muscles play important roles in basic functional activities, including balance control while standing,^{20,26} generation of torque during push-off while walking,^{3,27,33} and many other routine activities of daily living. Functional activities may be compromised in the elderly because strength is known to decline as a result of aging.^{7,12,16,30,34,36,37} Studies have shown that aging brings about a loss of functional motor units,^{5,6,8,9,23,32} a decrease in the number²³⁻²⁵ and the size^{1,10,19,23-25} of both slow twitch (type I) and fast twitch (type II) muscle fibers, and the possibility of selective atrophy of type II muscle fibers.^{1,2,19,24,25} Studies with older animals²² and with older humans^{6,19,32} have provided evidence of type I fiber grouping, probably the result of type II fiber denervation and subsequent reinnervation by axonal sprouting from type I motor units. The reduction in the number of functional motor units and muscle fiber atrophy partially account for the decreased muscle mass and strength deficits in the muscles of older people.^{4,9,18,23,32,37}

The decline of strength that

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occurs with aging is also associated with slower calf muscle contractile properties^{31,36,37} and decreased neurologic excitability.^{31,36} The calf muscles of older women have longer contraction times and longer one-half relaxation times.^{36,37} Studies of Hoffman (H) reflexes, an indirect measure of the excitability of the alpha motor neuron pool, have shown that the H-reflex amplitude is smaller and of longer duration in older women (>60 years) than in younger women (<33 years).^{31,36} The decreased H-reflex response has been partially explained by changes in central nervous system latencies, by decreased conduction velocities in the peripheral motor nerves, and by changes in the synaptic response at the neuromuscular junction.³¹

Taken together, the studies cited above have indicated that the calf muscles of older people are not only weaker, but are also activated more slowly than the calf muscles of younger people. Decreased calf muscle strength and speed of muscle activation appear to have negative implications for functional activities in the elderly, particularly when rapid actions or rapid reactions are required, such as walking briskly across a busy street or recovering balance after it is perturbed. For example, Bendall et al³ reported that calf muscle strength is significantly associated with decreased walking speed and that both strength and walking speed decrease with aging. Whipple et al³⁸ reported that the peak concentric isokinetic torque of plantar flexion (PF) was significantly less for nursing home residents with a history of falls compared to nursing home residents without a history of falls. They³⁸ also showed that the torque deficits were more obvious when tested at the faster velocity of $120^{\circ} \cdot s^{-1}$ than when tested at $60^{\circ} \cdot s^{-1}$. Given the apparent importance of calf muscle strength and the ability to develop torque rapidly, new testing methods that can detect age-related declines in relation to rapid PF movements are important to consider. The methods could potentially be used to establish objective baseline data and to study the effectiveness of therapeutic interventions designed to improve calf muscle strength in relation to rapid movements. Such interventions could potentially enhance calf muscle function or prevent decreased calf muscle function in time-essential functional actions that would otherwise be impaired by these age-related declines.

Several studies have investigated age-related changes in the maximal concentric isokinetic torque of the calf muscles.^{7,12,16,30,34} A significant decline in concentric PF through a slow-to-rapid velocity spectrum of $30^{\circ} \cdot s^{-1}$ to $180^{\circ} \cdot s^{-1}$ has been reported for older men⁷ and older women.^{12,16,34} In addition, calculating the rate of torque development at the slow isokinetic velocity of $30^{\circ} \cdot s^{-1}$ has been reported as a method for detecting age-related slower contractile properties of the calf muscles.^{29,30} The method, how-

ever, has not been reported for more rapid velocities, probably because technical problems during the acceleration phase of the moving armature at rapid velocities prohibit easy and accurate calculations.

On the basis of the evidence that aging brings about decreased calf muscle strength and concurrent slower contractile properties, we hypothesized that testing at rapid isokinetic velocities would show age-related characteristics that have not been reported previously. As a result, we designed an initial study¹⁶ to examine the influence of age on the concentric isokinetic torque characteristics when tested through a slow-to-rapid velocity spectrum of $30^{\circ} \cdot s^{-1}$, $60^{\circ} \cdot s^{-1}$, $120^{\circ} \cdot s^{-1}$, and $180^{\circ} \cdot s^{-1}$. The study differed from previous studies because concentric torque was measured from a starting position of maximal passive dorsiflexion (DF) that was defined separately for each subject. We believed this factor was important because the total torque produced by stretched skeletal muscles is well known to include the summation of the passive resistive torque and the active torque, both of which are influenced by the length of the muscles.¹⁴ The results of this initial study showed that the concentric isokinetic torque for the calf muscles was significantly less for older women (mean age, 71.1 ± 6.6 years; $n = 10$) than for younger women (mean age, 31.9 ± 6.1 years; $n = 10$).¹⁶ We also observed and reported a significant age-related decrease in the angular displacement from the onset of movement to peak torque at the 2 fastest isokinetic velocities of $120^{\circ} \cdot s^{-1}$ and $180^{\circ} \cdot s^{-1}$. This angular displacement, called "angular delay,"^{11,16,28} was decreased much more at $180^{\circ} \cdot s^{-1}$ than at $120^{\circ} \cdot s^{-1}$. Age was also negatively associated with the angular delay.¹⁶ Isokinetic angular delay has been reported previously for young subjects,^{11,28} but young, healthy subjects have been shown to reach peak torque at greater angular delays as the isokinetic velocity increases, a characteristic opposite from our initial findings with older women.¹⁶

The results of our initial study suggested that isokinetic testing at rapid velocities may provide a new method to detect age-related changes in the total concentric PF torque in relation to the velocity of movement, a characteristic probably influenced by slower muscle contractile properties. Accordingly, we designed the present study with a larger sample of subjects that included younger, middle-aged, and older women to conduct a more comprehensive comparative and correlational analysis. We believed that the present study was the logical next step and that it was needed to elucidate the internal and external validity of our initial findings.

The purposes of the present study, therefore, were 2-fold: (1) to examine, describe, and compare the age-related concentric isokinetic torque characteristics of the calf muscles of active younger, middle-aged, and older women when tested at slow to rapid

TABLE 1. Descriptive statistics for the age, height, mass, and body mass index (BMI) for the younger women (younger, $n = 24$), middle-aged women (middle, $n = 24$) and older women (older, $n = 33$).

| | Mean | SEM* | Range | 95% CIM† |
|-------------------|--------|------|---------------|---------------|
| Age, y | | | | |
| Younger | 29.67 | 1.26 | 20.00–39.00 | 27.05–32.28 |
| Middle | 50.21 | 1.25 | 40.00–59.00 | 47.62–52.80 |
| Older | 72.94 | 1.28 | 60.00–84.00 | 70.34–75.54 |
| Height, cm | | | | |
| Younger | 165.67 | 0.95 | 159.00–178.00 | 163.70–167.63 |
| Middle | 162.75 | 1.16 | 154.00–173.00 | 160.36–165.14 |
| Older | 158.76 | 0.91 | 150.00–175.00 | 156.90–160.61 |
| Mass, kg | | | | |
| Younger | 62.19 | 1.62 | 48.20–77.30 | 58.85–65.54 |
| Middle | 61.99 | 2.07 | 42.70–86.40 | 57.70–66.28 |
| Older | 60.80 | 1.23 | 49.10–79.60 | 58.30–63.30 |
| BMI | | | | |
| Younger | 22.63 | 0.51 | 18.83–27.07 | 21.58–23.67 |
| Middle | 23.32 | 0.63 | 16.89–28.87 | 22.02–24.63 |
| Older | 24.13 | 0.45 | 20.29–30.33 | 23.21–25.04 |

* Standard error of mean.

† Confidence interval of mean.

velocities; and (2) to check the validity of using the “angular delay” at velocities of $120^\circ \cdot s^{-1}$ and $180^\circ \cdot s^{-1}$ to detect age-related changes in the concentric torque production in relation to rapid PF. We hoped that the results would add to a more comprehensive understanding of the influence of age on the calf muscle function of women.

METHODS

Subjects

Eighty-one healthy, active women (age range, 20 to 84 years) participated in this study after giving informed consent. The women were divided into 3 age groups: 24 younger women (age range, 20 to 39 years); 24 middle-aged women (age range, 40 to 59 years), and 33 older women (age range, 60 to 84 years). Descriptive statistics for the subjects' age, height, mass, and body mass indexes ($BMI = \text{mass}[\text{kg}]/\text{height}[\text{m}]^2$) are presented in Table 1. Separate 1-way analysis of variance tests (ANOVAs) and Tukey post-hoc tests indicated that the older women were shorter than the younger and middle-aged women ($P \leq .015$), but the masses did not differ among age groups ($P = .79$). The subjects' BMIs also did not differ among groups ($P = .12$). The

TABLE 2. Method used to document the subjects' self-reported health status (A) and activity level (B), and the method of numeric scoring (not included in the interview).

| | | | |
|---------------------------------------------------------------------|-----------------|-------------------|----------------------|
| A. How would you rate your current health? (circle) | | | |
| Excellent (4) | Good (3) | Fair (2) | Poor (1) |
| B. Overall, how would you rate your activity level? (circle) | | | |
| Extremely Active (4) | Very Active (3) | Fairly Active (2) | Minimally Active (1) |

TABLE 3. Descriptive statistics for the self-assessed health rating and activity level for the younger women (younger, $n = 24$), middle-aged women (middle, $n = 24$), and older women (older, $n = 33$).

| | Mean | SEM | Range | K-W Test* | P Value |
|-----------------------|------|------|-----------|-----------|---------|
| Health Rating | | | | | |
| Younger | 3.46 | 0.10 | 3.00–4.00 | 0.71 | .058 |
| Middle | 3.79 | 0.09 | 3.00–4.00 | | |
| Older | 3.58 | 0.09 | 3.00–4.00 | | |
| Activity Level | | | | | |
| Younger | 2.29 | 0.14 | 1.00–3.00 | 2.98 | .225 |
| Middle | 2.63 | 0.15 | 2.00–4.00 | | |
| Older | 2.61 | 0.12 | 1.00–4.00 | | |

* A Kruskal-Wallis (K-W) test statistic showed no significant differences among groups.

study was approved by The University of Montana's Institutional Review Board for the Use of Human Subjects in Research.

None of the women had a history of orthopaedic or neurologic disorders, and they were considered nonsedentary and active for their particular age groups. They participated in routine regimens of moderate to strenuous physical activities such as gardening, walking, hiking, running, dancing, or aerobics. We attempted to include women with similar physical activity levels, but the amount and the intensity of the physical activities varied, both within and among the 3 groups. The subjects self-assessed their current general health status and they rated their current physical activity level based on the method reported in Table 2. These results showed no significant differences among the 3 groups (Table 3).

Instrumentation

Subjects were tested on a Kin-Com isokinetic dynamometer at a sampling rate of 100 Hz (Kinetic Communicator II 500H, Chattecx Corp., Chattanooga, Tenn). The Kin-Com ankle-foot apparatus was used to manually measure the maximal passive DF angle and to position the ankle at this angle for the start of the isokinetic tests. The concentric isokinetic torque (Nm) was adjusted for the effects of gravity and the torque of the apparatus.

Surface electromyography (EMG; GCS 67, Therapeutic Unlimited, Iowa City, Iowa) with on-site pre-amplification was used to monitor the activity of the medial head of the gastrocnemius, the soleus, and the tibialis anterior muscles to determine the maxi-

TABLE 4. Descriptive statistics and ANOVA results* for the maximal passive dorsiflexion (DF) angle and the maximal passive resistive DF torque for the younger women (younger, $n = 24$), middle-aged women (middle, $n = 24$), and the older women (older, $n = 33$).

| | Mean | SEM | Range | 95% CIM† | F ratio | P value |
|------------------------------------------|------|-----|-----------|-----------|---------|---------|
| Maximal passive DF angle (°) | | | | | | |
| Younger | 25.8 | 1.1 | 16.0–34.0 | 23.5–28.2 | 29.37 | <.001 |
| Middle | 22.8 | 0.9 | 16.0–34.0 | 20.9–24.6 | | |
| Older | 15.4 | 1.0 | –2.0–27.0 | 13.3–17.4 | | |
| Maximal passive resistive DF torque (Nm) | | | | | | |
| Younger | 21.7 | 1.1 | 10.2–31.0 | 19.4–23.9 | 19.49 | <.001 |
| Middle | 18.0 | 1.1 | 9.2–32.2 | 15.7–20.2 | | |
| Older | 12.6 | 1.0 | 3.2–25.2 | 10.6–14.6 | | |

*The ANOVAs showed significant group effects.

† Confidence interval of mean.

mal passive DF angle before isokinetic testing. The bandwidth of the frequency response was 40 Hz to 4 kHz. The common mode rejection ratio was 87 dB at 60 Hz, and the input impedance was greater than 25 MOhms at dc. The raw EMG signal was amplified ($\times 5000$) and monitored using an oscilloscope and computer to ensure that the maximal passive DF angle was determined initially without calf muscle activation, defined as <0.05 mV of raw EMG activity.

Procedures

With the right knee in full extension, each subject was screened initially using standard goniometric procedures to ensure that she had sufficient ankle range of motion (ROM) to complete the tests. The majority of the subjects had active ankle ROM that was greater than 60° , but 4 older subjects had active ankle ROM that was slightly less than 60° . All subjects then participated in a regimen of calf muscle stretching of 10 static stretches for 10 seconds each. Doing this regimen helped ensure that a maximal passive calf muscle-tendon length would be reached to define the maximal passive DF angle.

Each subject then lay in a supine position on the Kin-Com table with the right knee in extension and the right ankle aligned with the axis of the Kin-Com armature. All passive tests and subsequent concentric tests were conducted with the right knee in full extension in order to include the gastrocnemius muscle.^{11,12,16} The foot and ankle were secured to the ankle-foot apparatus with a bandage wrap and the subject was stabilized with cloth straps across the right knee, pelvis, right shoulder, and chest. The subject was encouraged to relax and the maximal passive DF angle and the maximal passive resistive DF torque were determined by moving the ankle slowly to the maximal DF angle without EMG activity in the muscles (<0.05 mV). The end point of motion was defined by a marked increase in EMG activity or by the subject's tolerance to the stretch, or both. This method ensured that the calf muscle-tendon unit was lengthened maximally as tolerated for each subject.

On the basis of this procedure the passive elastic resistance of the stretched calf muscle-tendon unit was included as a part of the total torque produced for all of the subsequent concentric muscle activations. The descriptive statistics and ANOVA results for the maximal passive DF angles and the maximal passive resistive DF torque among the 3 groups are reported in Table 4. ANOVA and Tukey post-hoc analyses indicated that the older women had less maximal passive DF ROM than the younger and middle-aged women ($P < .001$), but the DF angles for the younger and middle-aged women did not differ. The maximal passive resistive DF torque was also less for the older women ($P \leq .002$), but did not differ between the younger and middle-aged women.

After the maximal passive DF angle was determined, the ankle was moved through 60° into PF to define the stop angle (DF degrees were positive, PF degrees were negative, and 90° was defined as neutral [0°]). One older subject experienced discomfort with her ankle positioned in PF, so her PF ROM was decreased to 55° . After several submaximal practice trials at the 4 velocities, 3 maximal efforts were completed at each of the 4 randomly ordered velocities programmed at KIN-COM settings of $30^\circ \cdot s^{-1}$, $60^\circ \cdot s^{-1}$, $120^\circ \cdot s^{-1}$, and $180^\circ \cdot s^{-1}$. Subjects were given verbal encouragement to push as hard and as fast as possible through the full PF ROM. The ankle was returned to the maximal DF angle at $5^\circ \cdot s^{-1}$ between each trial of maximal concentric PF.

Data Reduction

The average absolute torque (Nm) among the 3 trials was determined for the peak torque and for the mean torque, which was defined as the mean of all data points through the PF ROM. Five degrees were deducted from the end of the PF ROM for all test velocities to account for deceleration artifacts observed at $120^\circ \cdot s^{-1}$ and $180^\circ \cdot s^{-1}$. Because one older subject was tested through 55° of PF, her mean torque was calculated through 50° of PF ROM. The average angular delay, defined as the angular dis-

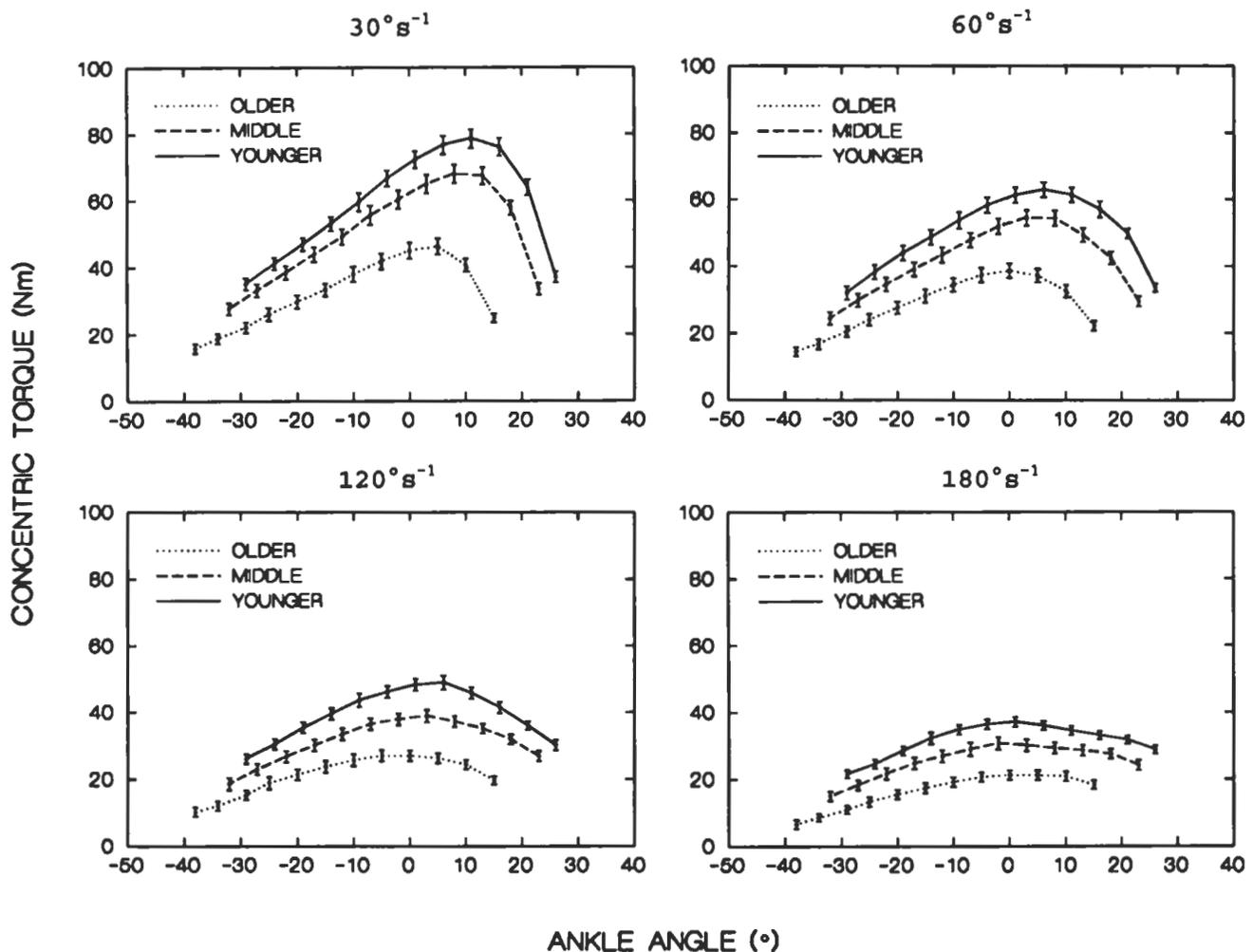


FIGURE 1. Concentric isokinetic torque curves (\pm SEM) at isokinetic velocities of $30^\circ \cdot s^{-1}$, $60^\circ \cdot s^{-1}$, $120^\circ \cdot s^{-1}$, and $180^\circ \cdot s^{-1}$ for the younger women ($n = 24$), middle-aged women ($n = 24$), and the older women ($n = 33$). (Dorsiflexion ankle angle is denoted by positive numbers [+]; plantar flexion ankle angle is denoted by negative numbers [-]).

placement from the onset of the movement to peak torque, was also determined among the 3 trials for each of the 4 test velocities.

The coefficient of variation ($CV = SD/\bar{x} \cdot 100$) of the mean torque through the PF ROM ranged from 3.74% to 7.41% among all test velocities for all groups. The small CVs indicated minimal variability among trials, which were considered very reliable within the test session.

Data Analysis

Descriptive statistics were tabulated for the absolute peak torque and mean torque, and concentric torque curves were plotted graphically. A multivariate ANOVA (MANOVA, Pillai Trace) was used to examine the dependent variables of peak torque, mean torque, and angular delay among the 3 groups and 4 velocities. This was followed by separate 2-way ANOVAs (3 [group] \times 4 [velocity]) for each of the 3 concentric torque variables. Significant group effects were followed by separate 1-way ANOVAs and Tukey

post-hoc analyses to examine group differences for each variable at each velocity. The Pearson product moment correlation coefficient (r) was used to examine the relationship of age to the maximal passive DF angle, the maximal passive-resistive DF torque, the peak and mean torques, and the angular delay. Statistical significance was set at $P \leq .05$.

RESULTS

The torque curves for $30^\circ \cdot s^{-1}$, $60^\circ \cdot s^{-1}$, $120^\circ \cdot s^{-1}$, and $180^\circ \cdot s^{-1}$ are presented in Figure 1. The curves for the older women were shifted to the left compared to the curves for the younger and middle-aged women because the older women had less maximal passive DF ROM. The descriptive statistics for the peak torque and mean torque are presented in Tables 5 and 6, respectively. Descriptive statistics for the angular delay to peak torque are presented in Table 7 and depicted in Figure 2.

The MANOVA indicated a significant group effect for the peak torque and mean torque, and the angu-

TABLE 5. Descriptive statistics for the peak torque (Nm) among the concentric isokinetic test velocities for the younger women (younger, $n = 24$), middle-aged women (middle, $n = 24$) and older women (older, $n = 33$).

| Test Velocities | Mean | SEM* | Range | 95% CIM† |
|------------------------------|-------|------|--------------|-------------|
| 30° · s⁻¹ | | | | |
| Younger | 79.48 | 2.85 | 50.80–104.80 | 73.60–85.37 |
| Middle | 69.17 | 2.74 | 48.60–97.00 | 63.50–74.84 |
| Older | 48.36 | 2.40 | 26.60–81.60 | 43.48–53.25 |
| 60° · s⁻¹ | | | | |
| Younger | 63.72 | 2.41 | 43.00–88.60 | 58.73–68.70 |
| Middle | 55.28 | 2.29 | 34.60–75.80 | 50.54–60.01 |
| Older | 40.15 | 2.16 | 23.80–72.40 | 35.75–44.54 |
| 120° · s⁻¹ | | | | |
| Younger | 48.19 | 1.78 | 30.80–68.60 | 44.51–51.88 |
| Middle | 38.76 | 1.56 | 25.40–55.00 | 35.54–41.98 |
| Older | 28.49 | 1.69 | 14.40–51.60 | 25.05–31.93 |
| 180° · s⁻¹ | | | | |
| Younger | 37.65 | 1.44 | 22.60–52.20 | 34.68–40.62 |
| Middle | 31.63 | 1.58 | 18.00–50.20 | 28.34–34.90 |
| Older | 23.35 | 1.44 | 12.20–42.40 | 20.40–26.29 |

* Standard error of mean.
† Confidence interval of mean.

lar delay among all isokinetic velocities (DF = 24,136; $F = 4.86$, $P < .001$). The separate 2-way ANOVAs for the peak torque, mean torque, and the angular delay each indicated significant effects for groups, test velocity, and interactions ($P < .001$). Separate ANOVAs and Tukey post-hoc analyses showed that the middle-aged women had significantly less peak torque and mean torque than the younger women at all test velocities ($P \leq .042$), and that the older women had significantly less peak torque and mean torque than both the younger and middle-aged women at all test velocities ($P \leq .001$).

The 1-way ANOVA and Tukey post hoc analyses indicated that the angular delay at 30° · s⁻¹ was less for the older women compared to the younger women ($P < .001$), and the angular delays at 60° · s⁻¹ and 120° · s⁻¹ were less for the older women than for both the younger and middle-aged women ($P \leq .009$). The angular delay at 180° · s⁻¹ showed a significant decrease with increasing age groups between all group comparisons ($P \leq .001$).

Age showed significant negative correlations with the maximal passive DF angle ($r = -0.73$) and the maximal passive-resistive DF torque ($r = -0.60$) ($P < .001$, $n = 81$). Age also was negatively correlated with the peak torque and mean torque, and angular delay for all test velocities ($P < .001$, $n = 81$) (Table 8). The negative correlation of age with angular delay increased as the test velocity increased from 30° · s⁻¹ ($r = -0.44$) to 180° · s⁻¹ ($r = -0.64$).

At the 180° · s⁻¹ programmed velocity, the acceleration phase of the Kin-Com armature required 9° to reach 180° · s⁻¹. Thus, the mean angular delay at 180° · s⁻¹ for the older women (8.03°) occurred with-

TABLE 6. Descriptive statistics for the mean torque (Nm) among the concentric isokinetic test velocities for the younger women (younger, $n = 24$), middle-aged women (middle, $n = 24$) and older women (older, $n = 33$).

| Test Velocities | Mean | SEM* | Range | 95% CIM† |
|------------------------------|-------|------|-------------|-------------|
| 30° · s⁻¹ | | | | |
| Younger | 60.85 | 2.04 | 38.40–74.80 | 56.63–65.07 |
| Middle | 51.30 | 2.11 | 33.80–72.40 | 46.95–55.66 |
| Older | 33.46 | 1.74 | 17.80–55.60 | 29.93–37.00 |
| 60° · s⁻¹ | | | | |
| Younger | 50.73 | 2.06 | 30.88–66.00 | 46.46–54.99 |
| Middle | 42.96 | 1.91 | 24.40–62.80 | 39.00–46.92 |
| Older | 29.77 | 1.66 | 15.00–50.20 | 26.40–33.16 |
| 120° · s⁻¹ | | | | |
| Younger | 39.68 | 1.40 | 23.00–50.80 | 36.79–42.57 |
| Middle | 26.07 | 1.47 | 18.20–48.40 | 28.92–35.00 |
| Older | 22.01 | 1.47 | 10.40–41.00 | 19.01–25.01 |
| 180° · s⁻¹ | | | | |
| Younger | 32.23 | 1.20 | 17.40–41.80 | 29.76–34.71 |
| Middle | 26.07 | 1.56 | 14.20–43.00 | 22.83–29.30 |
| Older | 17.30 | 1.28 | 8.20–34.80 | 14.70–19.90 |

* Standard error of mean.
† Confidence interval of mean.

in this acceleration phase. Examination of the stored ASCII data within the Kin-Com files at 180° · s⁻¹ indicated that the velocity at peak torque for this programmed velocity was: (1) younger women, 179° ± 0.6° · s⁻¹ (SEM); (2) middle-aged women, 171° ± 3.3° · s⁻¹ (SEM); and (3) older women, 163° ± 4.1° · s⁻¹ (SEM). A 1-way ANOVA showed a group effect for the velocity at which the subjects reached peak torque for the 180° · s⁻¹ test velocity ($P = .003$); the velocity at peak torque for the older women was

TABLE 7. Descriptive statistics for the 'angular delay' (°) to peak torque among the concentric isokinetic test velocities for the younger women (younger, $n = 24$), middle-aged women (middle, $n = 24$) and older women (older, $n = 33$).

| Test Velocities | Mean | SEM* | Range | 95% CIM† |
|------------------------------|-------|------|-------------|-------------|
| 30° · s⁻¹ | | | | |
| Younger | 14.29 | 0.59 | 9.00–18.00 | 13.06–15.52 |
| Middle | 12.54 | 0.55 | 7.00–19.00 | 11.41–13.67 |
| Older | 10.88 | 0.55 | 6.00–19.00 | 9.76–12.00 |
| 60° · s⁻¹ | | | | |
| Younger | 18.13 | 0.59 | 12.00–23.00 | 16.91–19.34 |
| Middle | 16.96 | 0.55 | 12.00–24.00 | 15.83–18.09 |
| Older | 14.49 | 0.58 | 9.00–26.00 | 13.30–15.67 |
| 120° · s⁻¹ | | | | |
| Younger | 22.21 | 0.69 | 15.00–29.00 | 20.77–23.64 |
| Middle | 19.42 | 0.99 | 8.00–27.00 | 17.36–21.47 |
| Older | 15.49 | 0.97 | 2.00–25.00 | 13.51–17.46 |
| 180° · s⁻¹ | | | | |
| Younger | 24.21 | 0.98 | 16.00–33.00 | 22.19–26.23 |
| Middle | 15.71 | 1.99 | 2.00–31.00 | 11.58–19.84 |
| Older | 8.03 | 1.14 | 0.00–23.00 | 5.71–10.35 |

* Standard error of mean.
† Confidence interval of mean.

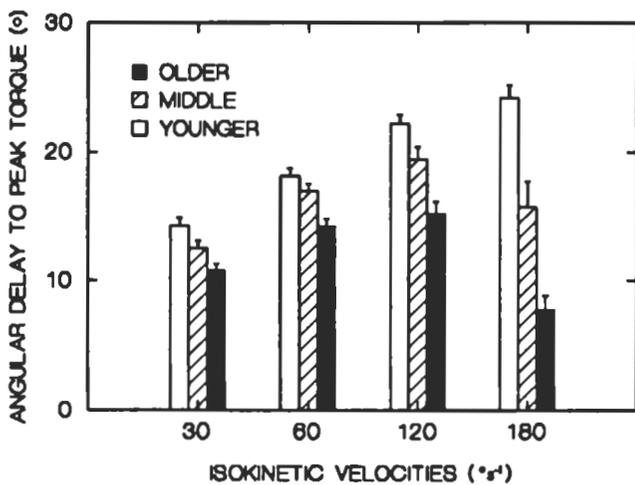


FIGURE 2. Bar graph showing the differences in the 'angular delay' (\pm SEM) to peak torque from the onset of concentric movement among groups for all isokinetic velocities. Note the marked decrease at $180^\circ \cdot s^{-1}$ for the middle-aged women ($n = 24$) and the older women ($n = 33$) compared to the younger women ($n = 24$).

less than for the younger women ($P = .002$). A follow-up correlational analysis showed that age was negatively associated with this velocity at peak torque (Pearson product moment $r = -0.29$, $P = .008$, $n = 81$).

DISCUSSION

The maximal concentric isokinetic torque produced by all of the women support previous findings that the torque across a slow-to-rapid velocity spectrum decreases in both younger and older people.^{7,12,16,34} These studies, with the exception of our previous report,¹⁶ tested concentric PF torque using subject positioning methods that differed from the methods that we used. Methods used by other investigators included testing from a starting position of active DF with the knee either flexed to 90° or extended,¹² testing from a position of active DF with the knee flexed to 20° ,³⁴ or testing with the knee extended and the DF ROM not reported.⁷ In addition, other age-related isokinetic studies have reported testing PF torque within a limited ROM that was common to all subjects (10° DF to 20° PF).^{29,30} We positioned the knee in full extension and we positioned the ankle at the maximal passive DF angle that was defined independently as tolerated for each subject. We held the knee in full extension in order to include the gastrocnemius muscle in the passive-resistive DF torque measurements and in the total concentric PF torque.^{11,12,16} We used this starting position because previous studies have demonstrated that the passive-resistive DF torque increases as the ankle is passively dorsiflexed, primarily explained by increasing the length of the calf muscle-tendon unit.^{16,39} Accordingly, maximal concentric PF from maximal passive DF measured the total PF torque

TABLE 8. Pearson product moment correlation coefficient values for relationships of age with concentric peak torque (Peak-T), concentric mean torque (Mean-T) and 'angular delay' to peak torque (AD) at the 4 isokinetic velocities for all women ($N = 81$).

| Correlated Parameters | Isokinetic Velocities | | | |
|-----------------------|-------------------------|-------------------------|--------------------------|--------------------------|
| | $30^\circ \cdot s^{-1}$ | $60^\circ \cdot s^{-1}$ | $120^\circ \cdot s^{-1}$ | $180^\circ \cdot s^{-1}$ |
| Age \times Peak-T | -0.65* | -0.63* | -0.68* | -0.60* |
| Age \times Mean-T | -0.73* | -0.67* | -0.70* | -0.66* |
| Age \times AD | -0.44* | -0.45* | -0.53* | -0.64* |

* $P < .001$.

produced because the passive elastic resistance from the maximal stretch was summed with the active component of the concentric torque produced. The results of the current study should be considered in light of these methodologic differences with previously published reports.

Because the onset of the PF movement was established at the maximal DF angle, the greater DF angle for the younger women shifted their torque curves to the right relative to a decrease in this DF angle for the older women that shifted their torque curves to the left (see Figure 1). Therefore, the absolute angle of peak torque, influenced by these different starting positions, differed among groups. The decreased maximal passive DF angle for the older women supports previous studies showing that the calf muscles shorten in older people.^{12,15,16,21,35} The significant decrease in the maximal passive-resistive DF torque for the older women, coupled with their significant decrease in total concentric PF torque, suggests that the size of the calf muscles and the associated connective tissues probably accounted for the decreased maximal passive-resistive DF torque. The atrophy^{4,9,18,23,32,37} and decreased muscle mass associated with aging^{4,9,18,23,32,37} is a plausible explanation for the decreased resistance to maximal passive muscle stretch.^{15,35} The significant negative associations of age with the maximal DF angle and with the maximal passive-resistive DF torque provide additional evidence that these variables decrease as a result of aging, even in healthy, active women. One may argue that these differences resulted because the calf muscles of the older women were not stretched maximally, but we have no evidence that this happened. On the basis of our operational definitions, the maximal DF ROM was defined in the same way for all subjects using an established protocol based on ethical considerations and approval by our Institutional Review Board for the Use of Human Subjects in Research.

The decrease in the total peak torque and mean torque for the older women is consistent with strength deficits that probably resulted from a loss of functional motor units,^{5,6,8,9} and a decrease in the number²³⁻²⁵ and the size^{1,10,19,23-25} of both type I and type II muscle fibers. The significant negative relationships between age and the peak torque and

mean torque provide additional evidence that the concentric torque of the calf muscles of healthy, active women decreases with age. Our results also indicated that a significant decline in concentric isokinetic torque of the calf muscles had already occurred in middle age (40 to 59 years). Previous reports have indicated no significant decline in the PF torque for women until after 50 years of age¹² or until after 60 years of age.³⁷

Previous studies have shown that during concentric isokinetic testing of the calf muscles, the peak torque for healthy young adults occurs at a greater angular delay from the onset of the PF movement as the isokinetic velocity increases.^{11,16,28} For example, Fugl-Meyer¹¹ tested the concentric isokinetic PF of healthy athletes and reported mean angular delays of 18°, 21°, 29°, and 33° for velocities of 30° · s⁻¹, 60° · s⁻¹, 120° · s⁻¹, and 180° · s⁻¹, respectively. The younger women in the current study had somewhat smaller mean angular delays (14°, 18°, 22°, and 24°, respectively) for the same velocities. These differences could have resulted from our use of different testing methods. Although the angular delays for the younger women in our study were smaller than those reported by Fugl-Meyer,¹¹ they showed the same pattern; they increased as the isokinetic velocities increased.

The angular delays for the older women in the current study were less than those for the younger women at all isokinetic velocities, and they showed a marked decrease for both the middle-aged women and the older women at 180° · s⁻¹. The differences at the 30° · s⁻¹, 60° · s⁻¹, and 120° · s⁻¹ velocities can be explained partially because the older women generated less peak torque than the younger women. In other words, the older women reached peak torque sooner because less torque was generated. At 180° · s⁻¹, however, the mean peak torque for the older women occurred within the acceleration phase of the Kin-Com armature and at a significantly slower velocity. This probably occurred because their calf muscles had slower contractile properties, and therefore, decreased speed of muscle activation and PF movement. The obvious decreased angular delays at 180° · s⁻¹ also were observed for the middle-aged women (40 to 59 years), which indicated that decreased speed of calf muscle activation had already begun in middle age. This apparent decreased speed of movement appeared to limit the subjects' ability to overcome the rapid velocity of the Kin-Com armature, and this shifted their angular delays toward the angle of the onset of the PF movement. The lack of significant differences among groups for the angular delay at 120° · s⁻¹ does not support the validity of testing at 120° · s⁻¹ to detect age-related changes.

We acknowledge that many factors could have contributed to the decreased angular delays, but the differences are in agreement with the previously refer-

enced studies that reported slower contractile properties of aging muscles^{31,36,37} and the possibility of selective loss of type II fibers.^{1,2,19,24,25} Denervation of type II fibers and reinnervation by axonal sprouting from type I motor units^{6,19,22,32} also could contribute to slower contractile properties, slower muscle activation, and slower PF movement. Human soleus muscles are dominated by type I fibers^{13,17} and human gastrocnemius muscles generally have equal distribution of type I and type II fibers.¹⁷ The changes in the angular delay that we observed could have resulted from fiber type changes in the gastrocnemius muscle primarily because the tests were conducted with the knees in full extension. Additional studies are needed to address this possibility.

Previous attempts to detect decreased contractile properties of the calf muscles using isokinetics have reported^{29,30} calculating the rate of torque development at the slow isokinetic velocity of 30° · s⁻¹. As mentioned earlier, this method does not appear applicable at rapid isokinetic velocities. Moreover, the method used to calculate the rate of torque development as it was reported did not appear to account for the angular delay from the onset of the movement³⁰ (see Figure 1). Calculating the rate of torque development at 30° · s⁻¹ could be a useful method, but the elapsed time used to calculate the rate of torque development must include the time from the onset of concentric movement.

Clinical Implications

Data comparing younger, middle-aged, and older women have not been reported previously. The descriptive results of the current study will serve as age-referenced comparisons of calf muscle maximal concentric isokinetic torque in active women from across most of the adult life span. On the basis of the reported confidence intervals of the mean, clinicians can be 95% confident that the true population means for active women would fall within the limits provided. Given that the older women in the current study were nonsedentary and active, greater differences in the angular delay might be found in older, sedentary women. This is important because noninvasive isokinetic testing at rapid velocities could be used to study the efficacy of physical training regimens and therapeutic interventions in older, sedentary people. This possibility is worthy of future studies to investigate whether the speed of movement and concentric torque can be enhanced using isokinetic training or other methods of training at rapid velocities. More research is needed to determine the influence of therapeutic training on improving functional performances in the elderly, including walking, running, and other routine physical activities.

The methods also have the potential for use in clinical studies of calf muscle function in patients

with conditions that influence calf muscle performance. For example, older patients with decreased passive DF ROM and decreased ability to generate PF torque rapidly, may have balance disturbances influenced by the limited ROM, and difficulty generating torque rapidly in response to sudden perturbations.²⁰ Objective measures of calf muscle impairments could help direct therapeutic interventions designed to ameliorate the impairments and potentially decrease falls in the elderly.³⁸ Clearly, more research is needed to investigate the most appropriate therapeutic strategies that would enhance functional performances. This may be particularly important for time-essential functional actions or reactions that would otherwise be impaired by the age-related declines in strength and speed of calf muscle activation.

CONCLUSION

The results showed that the concentric isokinetic peak torque and mean torque of the calf muscles were decreased for middle-aged women and for older women compared to younger women, but the decreases were most marked for the older women. The decreased angular delay from the onset of movement to peak torque for the middle-aged and older women at $180^\circ \cdot s^{-1}$ suggests that isokinetic testing at this rapid velocity offers a method to study changes in the total concentric PF torque in relation to rapid PF movement, probably influenced by age-related declines in calf muscle contractile properties. The results elucidate a practical application of noninvasive isokinetic testing to examine the influence of age on the ability of women to generate torque from the calf muscles during rapid PF of the ankle. The testing methods could be important clinically to detect age-related changes in calf muscle function and to help direct therapeutic interventions designed to enhance functional outcomes or to prevent age-related declines in calf muscle function during physical activities that require rapid lower extremity reactions.

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