Eur J Appl Physiol (1996) 74: 279–286

ORIGINAL ARTICLE

Richard L. Gajdosik · Darl W. Vander Linden
Ann K. Williams

Influence of age on concentric isokinetic torque and passive extensibility variables of the calf muscles of women

Accepted: 2 April 1996

Abstract The purpose of this study was to investigate the influence of age on concentric isokinetic torque (CIT) and passive extensibility (PE) variables of the calf muscles of healthy women. Ten younger women [31.9 (SD 6.1) years] and ten older women [71.1 (SD 6.6) years] were tested using a KIN-COM 500H dynamometer. The PE was tested by stretching the muscles from relaxed plantarflexion to the maximal dorsiflexion (DF) angle at $5° \cdot s^{-1}$ without raw electromyogram (EMG) activity exceeding 0.05 mV. The maximal CIT was tested from the maximal DF angle 60° into plantarflexion at four randomly ordered velocities of 30, 60, 120, and $180° \cdot s^{-1}$. Separate analysis of variance (ANOVA) tests showed that the standardized (% body mass) concentric peak and mean torques were lower for the older women for all isokinetic velocities ($p < 0.001$). The "angular delay" from the onset of concentric activation to peak torque was smaller for the older women at 120 and $180° \cdot s^{-1}$ ($p < 0.05$). Age showed negative relationships (Pearson r) with all standardized peak torques ($p \leqslant 0.001$) and mean torques ($p < 0.001$), and the "angular delay" at 120 and $180° \cdot s^{-1}$ ($p \leqslant 0.05$). Independent t-tests showed that the maximal DF angle and the change in the PE angle from an initial angle (defined at 10% of the maximal passive torque) to the maximal DF angle were less for the older women ($p < 0.05$). Age was negatively related to the maximal DF angle and the change in the PE angle ($p < 0.01$). The results suggest an age-related decrease in calf muscle CIT, muscle length and PE. The smaller "angular delay" for the older women at 120 and $180° \cdot s^{-1}$ indicates that CIT testing at rapid velocities can be used to examine age-related changes in calf muscle contractile properties in relation to rapid velocities of movement.

Key words Ankle · Skeletal muscles · Isokinetic · Strength · Aged · Extensibility

R.L. Gajdosik (✉) · A.K. Williams
Motor Control Research Laboratory, Physical Therapy Department, The University of Montana, Missoula, MT 59812, USA

D.W. Vander Linden
Physical Therapy Department, Eastern Washington University, Mail Stop 4, Cheney, WA 99004, USA

Introduction

Anatomical and physiological studies have indicated that aging brings about a loss of functional motor units (Brown et al. 1988; Compbell et al. 1973; Doherty and Brown 1993; Doherty et al. 1993), a decrease in both slow-twitch (type I) and fast-twitch (type II) muscle fibers (Aniansson et al. 1981; Grimby et al. 1982; Lexell et al. 1983, 1988), and the possibility of selective atrophy of type II fibers (Aniansson et al. 1986; Aoyagi and Shephard 1992; Essen-Gustavsson and Borges 1986; Grimby et al. 1982; Lexell and Downham 1992). Studies with humans have shown that spinal cord motoneurons and functional motor units decrease in number with advancing age (Lexell 1995). Furthermore, studies with aging rats (Kanda and Hashizume 1989) and with elderly people (Grimby et al. 1982; Ståiberg et al. 1989) 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 decreased muscle mass and strength deficits reported for the muscles of older people (Borges 1989; Grimby 1995; Lexell 1995).

Studies also have indicated that muscle contractile properties are altered by aging. Muscle responses to direct electrical stimulation of the tibial nerve indicate that older women have a depressed muscle response and a smaller maximal muscle twitch amplitude (Vandervoort and Hayes 1989), as well as longer contraction times and longer half relaxation times (Vandervoort and Hayes 1989; Vandervoort and McComas 1986).

Studies of Hoffman reflex testing, an indirect measure of the excitability of the alpha motoneuron pool, have shown that the Hoffman reflex amplitude is smaller and longer in duration in older women ($>$ 60 years) than in younger women ($<$ 33 years) (Sabbihi and Sedgwick 1982; Vandervoort and Hayes 1989). These differences may have resulted from central nervous system latency changes, decreased conduction velocities in the peripheral nerves, and from changes in the delay time at the neuromuscular junction. Taken together, these studies have indicated that the calf muscles of older people are weaker and activated more slowly than the calf muscles of younger people.

Non-invasive muscle strength testing has demonstrated that the maximal concentric isokinetic torque (CIT) of the calf muscles decreases with age (Cunningham et al. 1987; Fugl-Meyer et al. 1979b, 1980). A significant decline in strength was reported for both men and women across a velocity spectrum of 30, 60, 90, 120 and $180° \cdot s^{-1}$ after 50 years of age (Fugl-Meyer et al. 1980). Testing also demonstrated that in young healthy adults the peak force was achieved at a greater angular displacement from the onset of activation as the isokinetic velocity was increased. This phenomenon has been described as "angular delay" (Fugl-Meyer 1981; Fugl-Meyer et al. 1979a; Oberg et al. 1987). Based on the results of the aforementioned studies showing that the contractile properties of the calf muscles are slowed with aging, we hypothesized that the "angular delay" should show age-dependent changes at rapid isokinetic velocities.

In addition to the possibility that CIT, at rapid velocities would reflect changes in the contractile properties of aging calf muscles, analysis of the passive extensibility (PE) curve in the absence of electromyogram (EMG) activity can provide information about the mechanical PE of muscles (Gajdosik 1991; Gajdosik et al. 1990; Tabary et al. 1972; Tardieu et al. 1982). This is based on the shape and position of the PE curves in human muscles compared to the PE curves and the histological and histochemical adaptations in animal muscles. For example, the passive length-tension curves of denervated rat muscles were reported as being steeper, with limited length extensibility between the resting lengths and the maximal lengths when compared with controls (Stolov et al. 1970; Thomson 1955).

Denervated muscles immobilized in shortened positions showed muscle belly shortening in adult rats (Stolov et al. 1971), and in adult cats, with loss of up to 35% of the sarcomeres (Goldspink et al. 1974). Innervated muscles immobilized in the shortened position also demonstrated shortening adaptations by the loss of sarcomeres (Goldspink et al., 1974; Tabary et al. 1972; Williams and Goldspink 1973, 1978) and changes in the connective tissue of the muscles (Tabary et al. 1972; Williams and Goldspink 1984). Increased stiffness, represented by steeper length tension curves, has been associated with an increase in the amount of connective tissues in the muscle of older rats compared to younger rats (Alnaqeeb et al. 1984).

Studies of the maximal range of motion (ROM) of ankle dorsiflexion (DF) have indicated that the calf muscles of both men and women show gradual shortening beyond 70 years of age (Fugl-Meyer et al. 1980; James and Parker 1989). Whether other PE variables of the calf muscles of women are altered by aging has not been reported. As stated earlier, aging causes a reduction in the number of functional motor units and muscle mass. The lost muscle mass may be replaced by increased fat and connective tissue within the muscle (Overend et al., 1992; Rice et al., 1989; Vandervoort and McComas 1986; Vandervoort et al. 1986). Accordingly, the calf muscles of older women should show changes in the form and position of the PE curve compared to those of younger women. The purposes of this study, therefore, were twofold: (1) to measure the maximal CIT of the calf muscles of women across a velocity spectrum to test the hypothesis that isokinetic testing at rapid velocities would reflect known age-related changes in calf muscle strength and contractile properties, and (2) to examine the PE of the calf muscles of older women in light of the possible age-related changes in their passive properties.

Methods

Subjects

Ten non-sedentary, active younger women, 26–45 years of age, and ten non-sedentary, active older women, 60–81 years of age, participated having given informed consent. All women were considered active for their particular age groups. Although the intensity of activity varied among subjects, both within and between age groups, all subjects participated in exercise activities such as routine regimens of walking, hiking, running, dancing, or aerobics programs. The mean age, height, and mass for the younger women were 31.9 (SD 6.1) years, 163.4 (SD 7.5) cm, and 55.2 (SD 7.9) kg, respectively. The mean age, height, and mass for the older women were 71.1 (SD 6.6) years, 163.0 (SD 6.3) cm, and 60.8 (SD 10.4) kg, respectively. All women were without diagnosed neurological or orthopedic disorders. The study was approved by The University of Montana's Institutional Review Board for the Use of Human Subjects in Research.

Instrumentation

The KIN-COM isokinetic dynamometer (kinetic communicator II 500H, Chattecx, Chattanooga, Tenn., USA), was used for all testing. The KIN-COM ankle-foot apparatus was used to move the ankle passively into DF at $5° \cdot s^{-1}$ ($0.087\ rad \cdot s^{-1}$) to measure the PE, and for all CIT tests at $30° \cdot s^{-1}$ ($0.52\ rad \cdot s^{-1}$), $60° \cdot s^{-1}$ ($1.05\ rad \cdot s^{-1}$), $120° \cdot s^{-1}$ ($2.09\ rad \cdot s^{-1}$), and $180° \cdot s^{-1}$ ($3.14\ rad \cdot s^{-1}$). The forces were adjusted for the effects of gravity of the apparatus.

Surface EMG (GCS 67, Therapeutics Unlimited, Iowa City, Iowa, USA) with on-site preamplification was used to monitor the activity of the medial head of the gastrocnemius, the soleus and the tibialis anterior muscles during the PE tests. 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 MΩ at dc. The raw EMG was amplified ($\times 5000$) and monitored using an oscilloscope to ensure that the PE tests were without calf muscle activation, defined as < 0.05 mV.

Testing procedures

The active DF angle, active plantarflexion angle, and active ROM were measured initially using standard goniometric procedures. The PE tests were then completed, followed by the CIT tests. Prior to PE testing, all subjects participated in a regimen of calf muscle stretching to decrease the potential for systematic lengthening of the muscles during the PE tests. All PE and CIT tests were conducted using the right calf muscles with the subjects supine and the knees in full extension to ensure that the tests included the gastrocnemius muscle.

Passive extensibility tests

Subjects assumed a supine, relaxed position on the KIN-COM testing table. The surface EMG electrodes were affixed over the three muscle bellies, and the ankle was aligned with the KIN-COM armature axis and secured in the ankle-foot apparatus with a bandage wrap. Cloth stabilization straps were placed across the right knee, pelvis and chest. The right ankle was then moved passively to the maximal DF angle. This angle was confirmed by the subject, or the presence of EMG activity in the calf muscles, or both. The ankle was then moved through 60° into plantarflexion to the start angle [DF degrees were positive, plantarflexion degrees were negative, and 90° was defined as neutral (0°)]. After the subject was encouraged to relax and no EMG activity was observed, the ankle was moved passively by the KIN-COM through the 60° ROM into DF at $5° \cdot s^{-1}$ to the maximal DF angle for three trials. The results from three trials were averaged and stored for analysis.

Plantarflexion strength tests

The ankle was moved slowly at $5° \cdot s^{-1}$ into full ankle DF and the maximal passive resistance to maximal lengthening of the calf muscles was observed and recorded. After several brief submaximal practice trials, three maximal effort trials were completed at each of the four randomly ordered velocities programmed at KIN-COM settings of 30, 60, 120 and $180° \cdot s^{-1}$. Subjects were encouraged to push as hard and as fast as possible through the full 60° ROM into plantarflexion.

Passive extensibility measurements

All torque measurements were first expressed as absolute torque (Nm) and then standardized for analysis by representing the torque as a percentage of each subject's body mass. The point of initial passive torque (defined as 10% of the standardized maximal passive torque) defined the initial angle, an this angle represented an initial muscle length. The maximal DF angle represented the maximal muscle length. The PE variables of the initial angle, maximal DF angle, angular change between the two angles, standardized maximal passive torque, and standardized PE ratios (Δ angle/Δ standardized torque) were calculated. The PE angles were plotted against the standardized torque values at 5° intervals.

Strength test measurements

The absolute CIT (Nm) measurements also were standardized by representing the torque as a percentage of each subject's body mass. Accordingly, the standardized concentric peak torque and mean torque (through 55° ROM) for the three trials were determined. Five degrees of motion were deducted from the end of the 60° ROM to account for the deceleration artifact at 120 and $180° \cdot s^{-1}$. The average standardized peak and mean torques, and "angular delay" to peak torque were tabulated for each of the three trials at each of the four velocities. The standardized CIT curves were plotted at 5° intervals through the 55° ROM for graphic representation.

Statistics

Descriptive statistics for the active DF angle, active plantarflexion angle, and active ROM (± SEM) were tabulated and independent t-tests were used to examine group differences. Standardized CIT (± SEM) and PE (± SEM) curves were constructed and descriptive statistics for the CIT and PE variables were tabulated. Two-way analysis or variance (ANOVA) tests for repeated measurements were used to assess CIT variables among the four isokinetic velocities and between groups. Independent t-tests were used to assess group differences for the PE variables. The Pearson correlation coefficient (r) was used to examine the relationship between age and the CIT and PE variables. Statistical significance was set at $P \leqslant 0.05$.

Results

The active DF angle, active plantarflexion angle, and active ROM were less for the older women than for the younger ($P < 0.05$) (Table 1). The standardized CIT curves for 30, 60, 120 and $180° \cdot s^{-1}$ are presented in

Table 1 Descriptive statistics and results of independent t-tests for the active dorsiflexion (DF) angle, active plantarflexion (PF) angle, and active range of motion (ROM) for younger women ($n = 10$) and older women ($n = 10$). (SEM Standard error of the mean)

Parameter	Mean	(SEM)	Range	t	p
Active DF angle (°)					
Younger	11.30	(1.18)	7.00–17.00	− 3.27	0.004
Older	6.10	(1.06)	1.00–12.00		
Active PF angle (°)					
Younger	66.00	(2.99)	47.00–75.00	− 2.66	0.016
Older	57.30	(1.34)	51.00–63.00		
Active ROM (°)					
Younger	77.30	(3.08)	62.00–92.00	− 4.16	0.001
Older	63.40	(1.32)	60.00–72.00		

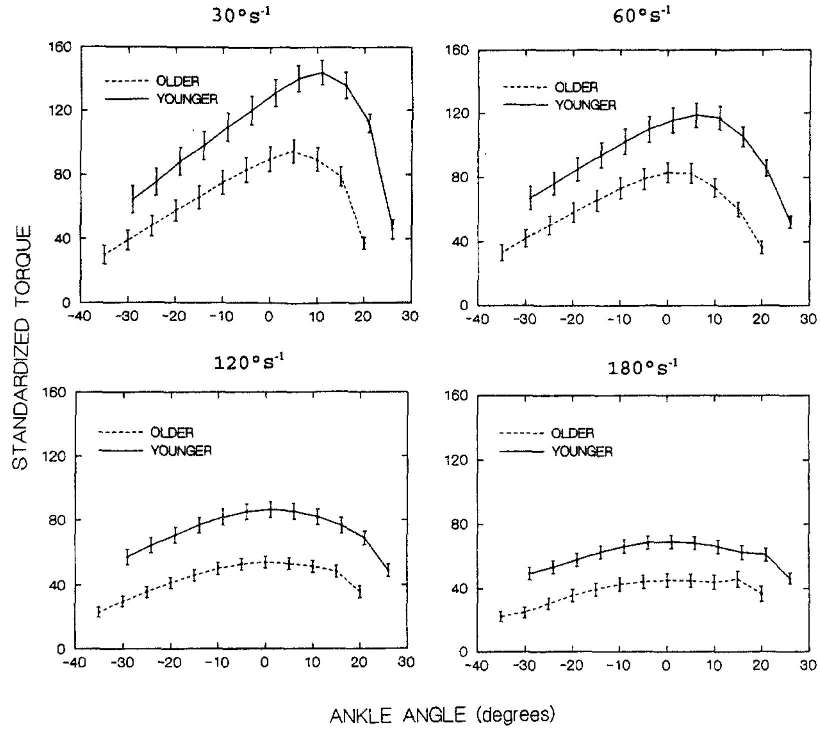

Fig. 1 Standardized[a] concentric isokinetic torque curves (SEM) measured at isokinetic velocities of $30°s^{-1}$, $60°s^{-1}$, $120°s^{-1}$, and $180°s^{-1}$ for older women ($n = 10$) and younger women ($n = 10$). Note the decreased torque and shift to the left for the older women. Dorsiflexion is denoted by *positive numbers*, plantarflexion by *negative numbers*. a % Body mass

Fig. 1. The curves for the older women were shifted to the left and depressed compared to those for the younger women. The standardized peak and mean torques for both groups among the four velocities are depicted in Fig. 2A and B, respectively. The "angular delays" to peak torque are depicted in Fig. 3. The ANOVA results showed a decrease in the peak and mean torques with increasing velocities ($P < 0.001$) for the older women ($P < 0.001$). The ANOVA results for the "angular delay" showed a significant effect among velocities ($P < 0.001$) and between groups ($P = 0.001$). Post-hoc univariant F-tests showed significantly smaller "angular delays" for the older women at $120° \cdot s^{-1}$ ($P = 0.038$) and $180° \cdot s^{-1}$ ($P < 0.001$). At the $180° \cdot s^{-1}$ programmed velocity, the acceleration phase of the KIN-COM armature required 9° to reach $180° \cdot s^{-1}$. Thus, the mean "angular delay" of $180° \cdot s^{-1}$ for the older women occurred within this acceleration phase (8°) (See Fig. 1). Further analysis of the $180° \cdot s^{-1}$ data indicated that the older women's mean velocity at peak torque was $140(15)° \cdot s^{-1}$ (SEM).

During the PE tests, the calf muscles were without EMG activity as operationally defined (< 0.05 mV). Increased EMG activity defined the maximal DF angle in some older and younger women, and increased EMG activities (shortening responses) were observed in the tibialis anterior muscle of a few subjects in both groups. The standardized PE curves for both groups are depicted in Fig. 4. The PE curves for the older

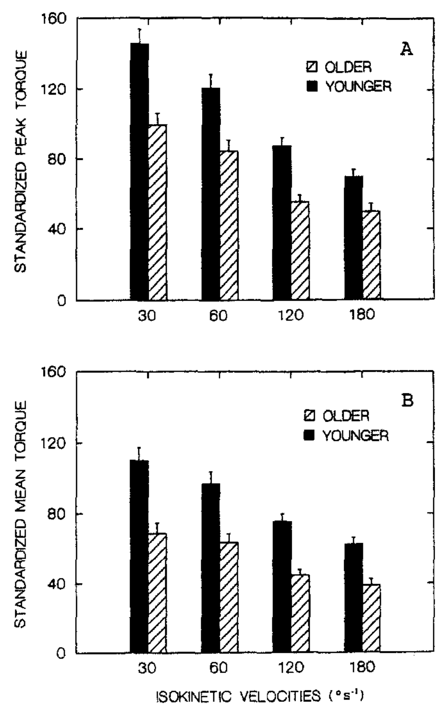

Fig. 2 Bar graphs showing A decreased standardized[a] concentric peak torque (SEM) as isokinetic velocities increased ($P < 0.001$), and B decreased standardized[a] concentric mean torque (SEM) through 55° ROM as isokinetic velocities increased ($P < 0.001$) for older women ($n = 10$) compared to younger women ($n = 10$). a % body mass

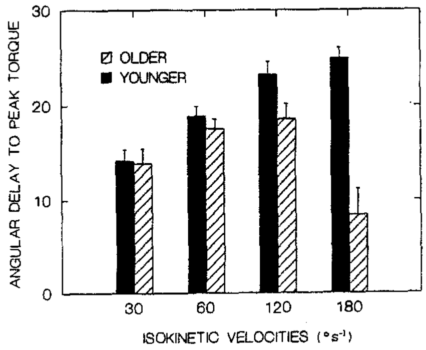

Fig. 3 Bar graph showing the decreased "angular delay" (SEM) to peak torque from the onset of concentric activation at $120°s^{-1}$ ($P = 0.038$) and $180°s^{-1}$ ($P < 0.001$) for older women ($n = 10$) compared to younger women ($n = 10$).

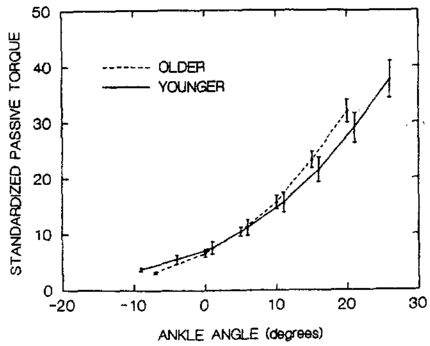

Fig. 4 Standardized[a] passive extensibility curves (SEM) for older women ($n = 10$) compared to younger women ($n = 10$). Note the decreased maximal dorsiflexion (DF) angle and decreased change in passive extensibility from the initial angle to the maximal DF angle ($P < 0.05$) for the older women. Dorsiflexion is denoted by positive numbers and plantarflexion by negative numbers. a % Body mass.

women were shifted left and appeared steeper. Descriptive statistics and the results of the independent *t*-tests for the PE variables are reported in Table 2. The maximal DF angle and the change in the PE angle were less for the older women than for the younger women ($P < 0.05$).

Age showed significant negative relationships with the peak and mean torques for all velocities ($P \leqslant 0.001$) and significant negative relationships with the "angular delay" at 120 and $180° \cdot s^{-1}$ ($P \leqslant 0.05$) (Table 3). Age also showed significant negative relationships with the maximal passive DF angle ($r = -0.62$, $P = 0.004$) and the change in the PE angle ($r = -0.75$, $P < 0.001$).

Table 3 Pearson correlation coefficient values for correlations of age with standardized concentric peak torque (*SCPT*), standardized concentric mean torque (*SCMP*) and "angular delay" to peak torque (*AD*) measured at four different isokinetic velocities for all women ($n = 20$).

Correlated parameters	Pearson correlation coefficient (r) at isokinetic velocities:			
	$30°s^{-1}$	$60°s^{-1}$	$120°s^{-1}$	$180°s^{-1}$
Age × SCPT	− 0.72*	− 0.69*	− 0.76*	− 0.69*
Age × SCMP	− 0.75**	− 0.73**	− 0.80**	− 0.75**
Age × AD	− 0.13	− 0.23	− 0.44***	− 0.79**

*$P \leqslant 0.01$
**$P < 0.001$
***$P < 0.050$

Table 2 Descriptive statistics and results of independent *t*-tests for the standardized maximal passive torque[a], maximal passive dorsiflexion (*DF*) angle, initial angle, change in passive extensibility (*PE*) angle, and standardized PE ratios[b] for younger women ($n = 10$) and older women ($n = 10$).

Parameter	Mean	(SEM)	Range	*t*	*p*
Standardized maximal passive torque					
Younger	37.73	(3.31)	25.56–57.24	1.47	0.160
Older	31.99	(2.00)	23.58–41.28		
Maximal DF angle (°)					
Younger	25.80	(1.88)	19.00–36.00	2.53	0.021
Older	20.10	(1.25)	15.00–26.00		
Initial angle (°)					
Younger	− 8.70	(1.21)	− 15.00 to − 2.00	− 0.96	0.349
Older	− 7.10	(1.14)	− 11.00 to 1.00		
Change in PE angle (°)					
Younger	34.50	(1.47)	28.00–42.00	3.80	0.001
Older	27.20	(1.24)	22.00–34.00		
Standardized PE ratio					
Younger	1.06	(0.06)	0.82–1.53	0.91	0.375
Older	0.98	(0.06)	0.71–1.20		

[a] Torque expressed as a percentage of body mass
[b] Change in angle/change in standardized torque

Discussion

The standardized CIT results support previous findings that the CIT across a slow-to-rapid velocity spectrum is decreased with age (Aniansson et al. 1986; Cunnngham et al. 1987; Fugl-Meyer et al. 1979b, 1980). The decrease in the peak and mean torques in the older women is consistent with the loss of functional motor units (Brown et al. 1988; Campbell et al. 1973; Doherty and Brown 1993; Doherty et al. 1993) and a decrease in both type I and type II muscle fibers (Aniansson et al. 1981; Grimby et al. 1982; Lexell et al. 1983, 1988). Because the onset of the CITs was established at the maximal DF angle, the decrease in this angle for the older women shifted their CIT curves to the left (compare Fig. 1 and 4). The significant negative relationships between age and the peak and mean torques provide additional evidence that calf muscle strength of non-sedentary, active women decreases with age.

Previous studies have shown that, during CIT testing, the peak force of healthy young adults was achieved at a greater "angular delay" from the onset of calf muscle activation as the isokinetic velocities were increased (Fugl-Meyer 1981; Fugl-Meyer et al. 1979a; Oberg et al. 1987). For example, Fugl-Meyer (1981) tested the concentric isokinetic plantarflexion of healthy athletes and reported mean "angular delays" of 18°, 21°, 29° and 33° for velocities of 30, 60, 120 and $180° \cdot s^{-1}$, respectively. The younger women in the current study had smaller mean "angular delays" (approximately 14°, 19°, 23°, and 25°) for the same velocities.

Although smaller, the "angular delays" showed the same trend: they increased as the velocities increased. The younger women of the current study were not trained athletes and this may partially explain the differences. The "angular delays" for the older women in the current study were similar to those for the younger women at isokinetic velocities of $30° \cdot s^{-1}$ (14°) and $60° \cdot s^{-1}$ (18°), but they were significantly less at $120° \cdot s^{-1}$ (19°) and at $180° \cdot s^{-1}$ (8°). These differences can be explained partially because the older women generated significantly less peak torque than the younger women at all velocities. Moreover, the results suggest that at 120 and $180° \cdot s^{-1}$ the older women reached peak torque sooner, because they had insufficient speed of muscle activation and movement. The insufficient speed of movement appeared to limit their ability to overcome the rapid velocity of the isokinetic armature and this shifted the "angular delays" toward the angle of the onset of activation. The smaller "angular delays" at both of the rapid velocities agree with the previously mentioned studies that reported slower contractile properties of aging muscles (Sabbahi and Sedgwick 1982; Vandervoort and Hayes 1989; Vandervoort and McComas 1986), and the possibility that there was selective loss of type II fibers (Aniansson et al. 1986; Aoyagi and Shephard 1992; Essen-Gustavsson and Borges 1986; Grimby et al. 1982; Lexell and Downham 1992).

Denervation of type II fibers and reinnervation by axonal sprouting from type I motor units (Grimby et al. 1882; Kanda and Hashizume 1989; Ståiberg et al. 1989) also could contribute to slower contractile properties and slower movements. Given that the older women in the current study were non-sedentary and active, greater differences in the "angular delay" might be found in sedentary older women. This possibility is particularly worthy of future investigations. Furthermore, non-invasive isokinetic testing at rapid velocities could be used to study the efficacy of physical training regimens and therapeutic interventions for older people. The methods also have the potential for use in clinical studies of calf muscle function for patients with peripheral neuropathies (Mueller et al. 1995).

The decreased active ROM measurements, and the decreased maximal DF angle and change in the PE angle support the results of previous studies indicating that the calf muscles of both men and women show shortening in older people (Fugl-Meyer et al. 1980; James and Parker 1989). The muscle shortening may have resulted from adaptations similar to those reported for animal muscles. Innervated animal muscles immobilized in the shortened position showed decreased muscle length, because of a reduction in the number of sarcomeres (Goldspink et al. 1974; Tabary et al. 1972; Williams and Goldspink 1973; 1978). The decreased maximal DF angle, combined with the decreased change in the PE angle, indicated that the length extensibility of the calf muscles of the older women was less than that for the younger women. This appears less extreme, but consistent with the PE characteristics of denervated animal muscles (Stolov et al. 1970; Thomson 1955). The decreased length extensibility is expected if the muscles were partially denervated, or not routinely lengthened maximally, or both. The significant negative relationships between age and the maximal DF angle and the change in the PE angle indicate that these two variables are particularly important to consider when examining age-related changes in calf muscle PE.

In addition to sarcomere loss, muscles immobilized in the shortened position have demonstrated greater abundance (Alnaqeeb et al., 1984; Tabary et al. 1972; Williams and Goldspink 1984) and remodeling (Williams and Goldspink 1984) of the connective tissue, resulting in greater tension per unit of passive elongation. This was represented by steeper passive length-tension curves. Although the standardized PE ratio of the older women in the current study was not significantly less than that of younger women, the PE curves appeared steeper (see Fig. 5). This finding is consistent with the results of studies showing that the lost muscle mass in older people may be replaced by increased fat and connective tissue within the muscles (Overend et al.

1992; Rice et al. 1989; Vandervoort and McComas 1986; Vandervoort et al. 1986). Further investigation is needed to examine the fat and connective tissue content of aged calf muscles concomitant with the examination of their PE characteristics.

In conclusion the results showed that the standardized concentric peak and mean torques of the calf muscles were decreased for older women compared with younger women. The decreased "angular delay" from the onset of activation to peak torque for the older women at 120 and $180^{\circ} \cdot s^{-1}$ suggests that CIT testing at rapid velocities may offer a non-invasive method to study the altered contractile properties of aged calf muscles. The CIT curves and the PE curves were shifted to the left for the older women, indicating muscle length shortening adaptations. The results elucidate the practical application of non-invasive CIT and PE testing in light of known anatomical and physiological changes underlying the influence of age on the concentric strength and PE of calf muscles of women.

Acknowledgements This study was supported in part by grants from The American Association of Retired Persons (AARP) Andrus Foundation, The M.J. Murdock Charitable Trust Foundation and The University of Montana. Special appreciation is extended to Pam Dietrich and Lori Bushway for their technical assistance.

References

Alnaqeeb MA, Al Zaid NS, Goldspink G (1984) Connective tissue changes and physical properties of developing and ageing muscle. J Anat 139:677–689

Aniansson A, Grimby G, Hedberg M, Krotkiewski M (1981) Muscle morphology, enzyme activity and muscle strength in elderly men and women. Clin Physiol 1:73–86

Aniansson A, Hedberg M, Henning G-B, Grimby (1986) Muscle morphology, enzymatic activity, and muscle strength in elderly men: a follow-up study. Muscle Nerve 9:585–591

Aoyagi Y, Shephard RJ (1992) Aging and muscle function. Sports Med 14:376–396

Borges O (1989) Isometric and isokinetic knee extension and flexion torque in men and women aged 20–70. Scand J Rehabil Med 21:45–53

Brown WF, Strong MJ, Snow R (1988) Methods for estimating numbers of motor units in biceps-brachialis muscles and losses of motor units with aging. Muscle Nerve 11:423–432

Campbell MJ, McComas AJ, Petito F (1973) Physiological changes in ageing muscles. J Neurol Neurosurg Psychlatry 36: 174–182

Cunningham DA, Morrison D, Rice CL, Cooke C (1987) Ageing and isokinetic plantar flexion. Eur J Appl Physiol 56:24–29

Doherty TJ, Brown WF (1993) The estimated numbers and relative sizes of thenar motor units as selected by multiple point stimulation in young and older adults. Muscle Nerve 16: 355–366

Doherty TJ, Vandervoort AA, Taylor AW, Brown WF (1993) Effects of motor unit losses on strength in older men and women. J. Appl Physiol 74:868–874

Essen-Gustavsson B, Borges O (1986) Histochemical and metabolic characteristics of human skeletal muscle in relation to age. Acta Physiol Scand 126:107–114

Fugl-Meyer AR (1981) Maximum isokinetic ankle plantar and dorsi flexion torques in trained subjects. Eur J Appl Physiol 47:393–404

Fugl-Meyer AR, Nordin G, Sjostrom M, Wahlby L (1979a) Achilles tendon injury 5. A model for isokinetic strength training and biofeedback. Scand J Rehabil Med 11:37–44

Fugl-Meyer AR, Sjostrom M, Wahlby L (1979b) Human plantar flexion strength and structure. Acta Physiol Scand 107:47–56

Fugl-Meyer AR, Gustafsson L, Burstedt Y (1980) Isokinetic and static plantar flexion characteristics. Eur J Appl Physiol 45:221–234

Gajdosik RL (1991) Passive compliance and length of clinically short hamstring muscles of healthy men. Clin Biomech 6:239–244

Gajdosik RL, Guiliani CA, Bohannon RW (1990) Passive compliance of the hamstring muscles of healthy men and women. Clin Biomech 5:23–29

Goldspink G, Tabary C, Tabary JC, Tardieu C, Tardieu G (1974) Effect of denervation on the adaptation of sarcomere number and muscle extensibility to the functional length of the muscle. J Physiol (Lond) 236:733–742

Grimby G (1995) Muscle performance and structure in the elderly as studied cross-sectionally and longitudinally. J Gerontol 50A:17–22

Grimby G, Danneskiold-Samsøe B, Hvid K, Saltin B (1982) Morphology and enzymatic capacity in arm and leg muscles in 78–81 year old men and women. Acta Physiol Scand 115:125–134

James B, Parker AW (1989) Active and passive mobility of lower limb joints in elderly men and women. Am J Phys Med Rehabil 68:162–167

Kanda K, Hashizumek (1989) Changes in properties of medial gastrocnemius motor units in aging rats. J Neurophysiol 61:737–746

Lexell J (1995) Human aging, muscle mass, and fiber type composition. J Gerontol 50A:11–16

Lexell J. Downham DY (1992) What is the effect of ageing on type 2 muscle fibers? J Neurol Sci 107:250–251

Lexell J, Henriksson-Larsen K, Winblad B, Sjostrom M (1983) Distribution of different fiber types in human skeletal muscles: effects of aging studied in whole muscle cross sections. Muscle Nerve 6:588–595

Lexell J, Taylor CC, Sjostrom M (1988) What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. J Neurol Sci 84:275–294

Mueller MJ, Minor SD, Schaaf JA, Strube MJ, Sahrmann SA (1995) Relationship of plantar-flexor peak torque and dorsiflexion range of motion to kinetic variables during walking. Phys Ther 75:684–693

Oberg B, Bergman T, Tropp H (1987) Testing of isokinetic muscle strength in the ankle. Med Sci Sports Exerc 19:318–322

Overend TJ, Cunningham DA, Paterson DH, Lefcoe MS (1992) Thigh composition in young and elderly men determined by computed tomography. Clin Physiol 12:629–640

Rice CL, Cunningham DA, Paterson DH, Lefcoe MS (1989) Arm and leg composition determined by computed tomography in young and elderly men. Clin Physiol 9:207–220

Sabbahi MA, Sedgwick EM (1982) Age-related changes in monosynaptic reflex excitability. J Gerontol 37:24–32

Ståiberg E, Borges O, Erickson B, Essén-Gustavsson B, Fawcett PRW, Nordesjö LO, Nordgen B, Uhlin R (1989) The quadriceps femoris muscle in 20–70-year-old-subjects: relationship between knee extension torque, electrophysiological parameters and muscle fiber characteristics. Muscle Nerve 12:382–389

Stolov WC, Weilepp TB Jr, Riddell WM (1970) Passive length-tension relationship and hydroxyproline content of chronically denervated skeletal muscle. Arch Phys Med Rehabil 51: 517–525

Stolov WC, Riddell WM, Shrier KP (1971) Effect of electrical stimulation on contracture of immobilized, innervated and denervated muscle (abstract). Arch Phys Med Rehabil 52:589

Tabary JC, Tabary C, Tardieu C, Tardieu G, Goldspink G (1972) Physiological and structural changes in the cat's soleus muscle due to immobilization at different lengths by plaster casts. J Physiol (Lond) 224:231–244

Tardieu C, Huet de la Tour E, Bret MD, Tardieu G (1982) Muscle hypoextensibility in children with cerebral palsy: I. Clinical and experimental observations. Arch Phys Med Rehabil 63:97–102

Thomson JD (1955) Mechanical characteristics of skeletal muscle undergoing atrophy of degeneration. Am J Phys Med 34: 606–611

Vandervoort AA, Hayes KC (1989) Plantarflexor muscle function in young and elderly women. Eur J Appl Physiol 58:389–394

Vandervoort AA, McComas AJ (1986) Contractile changes in opposing muscles of the human ankle joint with aging. J Appl Physiol 61:361–367

Vandervoort AA, Hayes KC, Belanger AY (1986) Strength and endurance of skeletal muscle in the elderly. Physiother Can 38:167–173

Williams PE, Goldspink G (1973) The effect of immobilization on the longitudinal growth of striated muscle fibers. J Anat 116:45–55

Williams PE, Goldspink G (1978) Changes in sarcomere length and physiological properties in immobilized muscle. J Anat 127:459–468

Williams PE, Goldspink G (1984) Connective tissue changes in immobilized muscle. J Anat 138:342–350