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Effects of Age on Rapid Ankle Torque Development

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Background. When balance is disturbed, often only fractions of a second are available in which to make the initial responses needed for its restoration. Abilities to develop joint torques rapidly may be critical to such responses. We undertook this study to quantify age effects among healthy adults in abilities to develop ankle joint torques rapidly.

Methods. Ankle dorsiflexion (DF) and plantarflexion (PF) torque development during rapid isometric and during isokinetic (30, 60, 120, 180, and 240 deg/sec) exertions was assessed in 24 healthy young (mean age 23 years) and 24 healthy old adults (mean age 72 years). The effects of age, gender, and torque direction on the times needed to reach given torque magnitudes, maximum rates of isometric torque development (MRTD), and maximum isokinetic torques were examined.

Results. The old adults required substantially more time to reach given torque magnitudes than the young adults. For example, the young and old females needed approximately 236 and 337 msec to develop 15 Nm of DF torque, of which 141 and 164 msec were reaction times. Isometric MRTD were 25 to 36% lower in the old than in the young adults. The age declines in isometric torque development time were associated with losses in maximum isometric strength. Maximum isokinetic torques developed by the old were 20 to 40% lower than those of young adults. The percent losses in isokinetic torques with age were independent of joint angular velocity for PF, but increased with velocity for DF.

Conclusions. We found substantial age declines in abilities of healthy old adults to rapidly develop ankle joint torques. The capacities of even healthy old adults to recover balance or to carry out other time-critical actions that require moderate-to-substantial strengths may be considerably degraded by these declines.

RECOVERY of balance upon a postural disturbance requires the development of moderate-to-substantial joint torques within short times. For example, the critical initial phases of both sway (1) and stepping (2,3) responses to disturbances of upright stance occur within 300 to 400 msec of the disturbance, but maximum knee extension torque, for example, cannot be developed this quickly (4,5,6). Thus, in many balance recovery situations the time available for recovery may not be sufficient to develop maximum joint torques. This suggests that the magnitudes of joint torques that can be developed within given times, rather than maximum strengths, can be important biomechanical factors limiting abilities to recover balance and to make other rapid movements that require moderate to substantial strengths.

It is well known that significant losses occur with age in isometric joint torque strengths [e.g., as reviewed by Schultz (7)], but the effects of age on rates of isometric torque development and on isokinetic torque development capacities are less explored. Clarkson et al. (5) found the times to reach absolute magnitudes of torque in knee extension to be significantly longer in the elderly, but found no age difference in the times needed to reach given percentages of maximum voluntary strength (MVS). In contrast, Häkkinen and Häkkinen (6) found significant differences between young and old groups in the time required to reach both specific absolute and normalized isometric knee extension torques. For isokinetic torques, no substantial age differences have been found in the shape of the normalized torque-velocity curves for knee extension (8) or ankle plantarflexion (9). However, elderly fallers compared to elderly controls demonstrated larger percent losses in high-velocity compared to low-velocity isokinetic dorsiflexion torques (10). It is not yet fully clear how aging affects rapid strength development capabilities at different joints of the human body.

We undertook the present study to gather additional data relevant to rapid development of joint torques. Ankle dorsiflexors and plantarflexors were selected for examination because of their importance in restoring balance after disturbances of standing posture by sway (11,12) and by stepping responses (13), and when tripping occurs during gait (14). We tested null hypotheses that age does not affect the time needed to develop given magnitudes of torque or maximum rates of isometric torque development (MRTD) during rapid isometric exertions, nor maximum torque during isokinetic exertions. Secondary objectives were to determine the effect of practice on rapid strength development and to determine how well various strength/time measures correlate with each other.

METHODS

Subjects. — Twenty-four healthy young (YA, age range 19–29 years) and 24 healthy old (OA, age range 65–86 years) adults, with equal numbers of males and females in the two age groups, participated in this study. The young females (YF, mean age 23.4 years) and young males (YM, 23.4 years) were recruited from University staff and students. Old females (OF, 74.2 years) and old males (OM, 69.9 years) were independently dwelling community members recruited from social support and recreational programs sponsored by a University-affiliated geriatrics clinic and from volunteers participating in the Claude Pepper Geriatric Research and Training Center Human Subjects Core. All but one of the OA were physically active, with regular participation in walking, exercise, or sports activities. The YA were significantly ($p < .05$) taller than the OA and the males were significantly taller ($p < .0001$) than the females (mean heights for YF, YM, OF, and OM were 165.3, 177.0, 158.9, and 174.3 cm). Body masses were significantly ($p < .0001$) larger in the males but did not differ significantly between the age groups (means for YF, YM, OF, and OM were 59.4, 72.9, 60.0, and 74.5 kg). The maximum circumferences of the lower leg also were significantly ($p < .01$) larger in the males but did not differ significantly between the age groups (means for YF, YM, OF, and OM were 34.7, 36.6, 34.0, and 35.8 cm).

All OA underwent a standardized medical history and physical examination performed by a nurse clinician under the supervision of a physician geriatrician. These focused on neurological and musculoskeletal findings. Eleven of these subjects were found to have experienced rare, occasional pain in the lower extremities or lower back in the past that was presently not a problem; 10 had decreased lower extremity reflexes; two had reduced vibration sense at the medial malleolus; and one had decreased position sense at the great toe.

Experimental methods. — All tests used an isokinetic dynamometer (MERAC, Universal Gym Equipment, Cedar Rapids, IA) that was custom instrumented for this study. Subjects lay supine, with arms placed alongside the body and hands grasping fixed handles to provide postural stability. Body motions other than ankle rotation were further restricted by straps over the lower leg, upper leg, waist, and shoulders. The preferred foot, defined as the foot the subject selected to kick a ball, was strapped to a footplate attached to the dynamometer, with the axis of sagittal ankle rotation aligned with the dynamometer axis. Knee angle was kept at 20 degrees short of full extension. Ankle angle was kept at 100 and 85 degrees during isometric dorsiflexion (DF) and plantarflexion (PF) exertions, respectively. These ankle angles correspond approximately to the angles at which maximum DF and PF torques can be developed (15,16).

Footplate angular position and exerted ankle torque were continuously monitored, the former using an optical encoder with a 90 count/deg resolution, and the latter using a torque cell mounted on the dynamometer axis. The torque cell signal was analog low-pass filtered with a breakpoint at 100 Hz to attenuate dynamometer motor controller noise of approximately 2 kHz. Myoelectric signals were recorded from the tibialis anterior, soleus, and medial and lateral gastrocnemius muscles using bipolar surface electrodes, but those data are analyzed and reported elsewhere (17).

Subjects developed joint torques isometrically and isokinetically. They were asked to "push down on" (PF) or "pull up on" (DF) the footplate "as fast and as hard as possible" in response to a visual cue. This cue was provided by a photoflash lamp of 6 cm diameter, mounted on a white background and located approximately 1 m directly above the subject's eyes. The lamp was programmed to flash after a random delay of 1 to 2 sec following an aural warning cue. The random delay prevented subjects from anticipating the flash. Data were acquired from 0.5 sec prior to 5.0 sec following the light flash cue, with $t = 0$ set to the time at which that cue was given. Subjects were strongly encouraged to make maximum efforts, and feedback on the torque magnitudes attained was verbally provided. During isometric tasks, the footplate was held at the preset angle and subjects were asked to maximally push or pull until hearing a tone which sounded 3 sec after the flash. Isokinetic tasks started from maximum DF and PF angles during PF and DF exertions, respectively. Subjects were asked to maximally push or pull throughout their available range of ankle motion. The subjects performed isokinetic tasks at nominal angular velocities of 30, 60, 120, 180, and 240 deg/sec.

Subjects performed 30 exertions in PF followed by 30 exertions in DF. Of these 30 trials, 12 were initial trials, consisting of six submaximum and six maximum practice exertions, which enabled subjects to become familiar with the tasks. The remaining 18 trials, from which data were collected, were performed in three identical blocks of six trials each, to examine the effects of the additional practice. In each block, one exertion was performed isometrically and one exertion was performed at each of the five isokinetic nominal velocities. The six exertions were performed by each subject in each block in the same initially randomized, fixed sequence. Subjects rested approximately 30 sec between trials and 5 min between blocks.

Data analysis. — Position encoder, torque cell, and flash trigger signals were simultaneously digitized at 1400 Hz using a 12 bit A/D board and stored in computer memory. Angular position and exerted torque signals were digitally low-pass filtered using a sixth-order Butterworth Filter with a 30 Hz cutoff frequency. Angular velocities and accelerations were then calculated from the position data, using a 5-point numerical differentiation scheme. The net ankle torque was calculated using an inverse-dynamics model of the lower leg that accounted for all external weight and inertial forces acting on it. The applied torque was the dominant component of the net ankle torque. Inertial torques were relatively small, reaching maximum magnitudes of approximately 3 Nm during the acceleration phase of the highest velocity isokinetic exertions. Weight torques resulted primarily from the weight of the footplate and averaged 0 to 2 Nm, depending on the rotation angle.

During the isometric tasks the following measures were derived from the ankle torque signals: Reaction time (RT), maximum voluntary strength (MVS), times to develop various absolute magnitudes of joint torque and to develop 50% of MVS, maximum rate of torque development (MRTD), and normalized maximum rate of torque development (NRTD). RT was defined as the time between the onset of the visual cue and the onset of ankle torque development. RT was calculated by identifying the times at which 1 and 2% of MVS were reached and linearly extrapolating to the theoretical torque development onset time. MVS was defined as the maximum absolute ankle torque developed during any of the three isometric exertions. MRTD was defined as the maximum absolute instantaneous rate of torque development, with the rate (velocity) of torque development estimated using a 5-point numerical differentiation. NRTD were obtained by dividing the MRTD by the isometric MVS for that subject and direction.

During the isokinetic tasks, maximum ankle torques and associated angular velocities were derived from the torque and position signals. The maximum isokinetic torques across the three trials were normalized to the maximum isometric MVS recorded for the individual. During the high-velocity (180 and 240 deg/sec) isokinetic DF exertions, the measured rotation velocities of some old subjects often were substantially below the nominal velocities (Figure 2). For this reason, statistical comparisons of age effects on isokinetic torques were made only for rotation rates up to 120 deg/sec.

Statistical analyses. — Means and standard deviations of each variable were calculated for the subject groups. Repeated measures analysis of variance (ANOVA) was used to test for practice effects from the first to the third blocks in the isometric measures. ANOVA was used to test the effect of age, gender, and torque direction on RT, on times to reach absolute magnitudes of torques and to reach 50% of MVS and on NRTD. Due to the substantial differences in absolute strengths between genders and between torque directions, MVS and MRTD were stratified by gender and torque direction, and individual *t*-tests were used to test for the effects of age. Repeated measures ANOVA was used to test for the effects of age and angular velocity on normalized isokinetic torques. *P*-values $< .05$ were considered statistically significant throughout. The degree of association among RT, MRTD, MVS, and maximum isokinetic powers was measured by Pearson correlation coefficients. Isokinetic power (torque $\times$ measured angular velocity) rather than torque was used for this purpose because, as already noted, the measured angular velocities of some old subjects were substantially below the 180 and 240 deg/sec nominal velocities.

Results

Reaction times. — RTs were significantly affected by age and gender (Table 1) but were independent of torque direction. Mean RTs for the OA were 163 msec, which was 7% longer than the 153 msec mean RT for the YA.

Table 1. Effect of Age, Gender, and Torque Direction on Mean Reaction Time, Times Required To Reach Given Torque Magnitudes, and Time Required To Reach 50% of Maximum Voluntary Strength (times in msec)

	Young Females	Old Females	Young Males	Old Males
Dorsiflexion				
Reaction Time[5,9]	141 (12)	164 (28)	157 (20)	166 (30)
Additional Time To Reach				
5 Nm[6]	39 (8)	52 (12)	36 (15)	36 (7)
10 Nm[2,3,10]	64 (13)	94 (25)	56 (20)	61 (12)
15 Nm[1,2,8]	95 (24)	173 (76)	74 (26)	89 (21)
Total Time To Reach				
5 Nm	180	216	193	202
10 Nm	205	258	213	227
15 Nm	236	337	231	255
Additional Time to 50% MVS[11]	74 (9)	87 (19)	92 (27)	95 (21)
Total Time to 50% MVS	215	251	249	261
Plantarflexion				
Reaction Time[5,9]	145 (24)	160 (20)	161 (22)	166 (22)
Additional Time To Reach				
20 Nm[2,3]	74 (12)	104 (37)	57 (9)	67 (13)
40 Nm[4,5]	113 (20)	224 (163)	84 (16)	104 (27)
60 Nm[4,7]	166 (54)	312 (264)	109 (26)	147 (52)
Total Time To Reach				
20 Nm	219	264	218	233
40 Nm	258	384	245	270
60 Nm	311	472	270	313
Additional Time to 50% MVS[11]	150 (25)	156 (62)	133 (21)	148 (46)
Total Time to 50% MVS	295	316	294	314

Note. Means exclude any subjects for whom the torque magnitudes exceeded 90% of their MVS. The reaction times and additional times to reach the given torque magnitudes reflect the minimum times over the three trials. The total times are merely the sums of the reaction and additional times, so these were not statistically analyzed. *SD* in parentheses.

Significant differences by ANOVA:
[1] $p < .001$ for age
[2] $p < .001$ for gender
[3] $p < .005$ for age
[4] $p < .005$ for gender
[5] $p < .01$ for age
[6] $p < .01$ for gender
[7] $p < .02$ for age
[8] $p < .02$ for age $\times$ gender
[9] $p < .05$ for gender
[10] $p < .05$ for age $\times$ gender
[11] $p < .001$ for direction

Isometric torque development times and rates. — OM and OF required substantially more time to reach absolute torque magnitudes than YM and YF, respectively (Figure 1, Table 1). For example, in the mean, YF needed 236 msec to develop 15 Nm of DF torque, while OF required 337 msec to reach that torque magnitude. Correspondingly, absolute MRTD were significantly lower in the OA than in the YA in both DF and PF (Table 2). The loss in MRTD with age was 32 and 25% (females and males) in DF and 36 and 29% in PF. The times required to reach specific percentages of MVS were similar for both YA and OA (Figure 1). Were reaction times to be subtracted from these curves, they would nearly coincide. NRTD were slightly larger for the YA than the OA, but the difference was not significant (Table 2). Normalized torque magnitudes were achieved noticeably more slowly in PF than in DF for both YA and OA. Times to reach 50% of MVS ranged from 294 to 316 msec in PF, substantially longer than the 215 to 261 msec values in DF (Table 1).

Maximum voluntary isometric strengths. — The mean isometric MVS for the YF and YM were 28 and 43 Nm in DF, and 130 and 181 Nm in PF, respectively. Isometric MVS for the old were 21% (OF) and 14% (OM) smaller than those of the young in DF, and 32 and 24% smaller than those of the young in PF. These age-group differences were significant for both males and females, with the exception of DF in the males (Table 2).

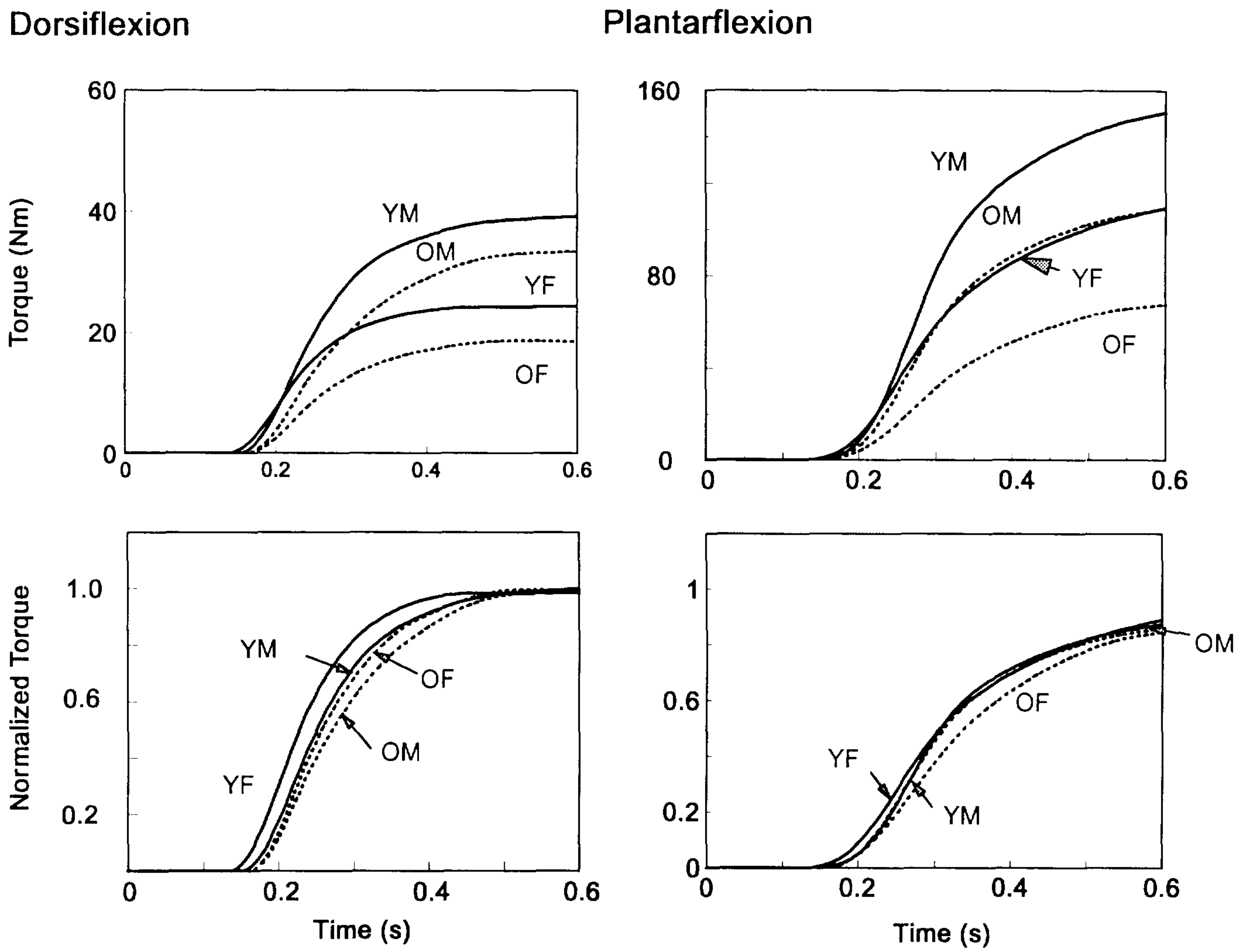

Figure 1. Mean absolute and normalized torque-time histories in isometric dorsiflexion and plantarflexion. YF = young females, OF = old females, YM = young males, OM = old males. Only data over the first 0.6 sec of the responses are shown, but response data were acquired for 5.0 sec. Normalization is to maximum voluntary isometric strength.

Table 2. Effect of Age on Maximum Voluntary Strength (MVS) and Maximum Absolute (MRTD) and Normalized (NRTD) Rates of Torque Development in Isometric Tests

	Direction	Young Females	Old Females	*p*-value*	Young Males	Old Males	*p*-value*
MVS (Nm)	DF	28 (4)	22 (3)	< .001	43 (8)	37 (5)	n.s.
	PF	130 (27)	88 (21)	< .001	181 (38)	137 (32)	< .01
MRTD (Nm/sec)	DF	219 (54)	148 (36)	< .001	309 (77)	232 (35)	< .005
	PF	608 (169)	389 (171)	< .005	957 (248)	681 (223)	< .01
NRTD (MVS/sec)†	DF	8.4 (1.0)	7.6 (1.5)	n.s.	7.6 (1.5)	6.5 (0.6)	n.s.
	PF	4.8 (0.8)	4.6 (1.3)	n.s.	5.5 (0.8)	5.3 (1.7)	n.s.

Note. *SD* in parentheses.

*Significant age effects determined by individual *t*-tests.

†This is expressed in multiple of MVS per sec.

Effects of practice on isometric strengths. — Some PF measures changed significantly between the first and third isometric strength trials. MRTD and MVS in PF increased ($p < .005$) 19.1% and ($p < .0001$) 8.1%, while RT decreased ($p < .05$) 5.3%. Mean changes from the first to third trials in DF measures were not significant.

Isokinetic torque development. — YA developed significantly larger maximum isokinetic torques than OA at all nominal velocities examined (Figure 2, Table 3). The normalized torque-velocity curves in PF were similar for young and old. In DF, significant age decrements in normalized torques were found, and they became larger with increasing velocity (Figure 2).

Correlations among isometric and isokinetic measures. — Isometric MRTD and MVS and isokinetic peak powers at the five nominal rotation velocities intercorrelated generally with correlation coefficients exceeding 0.8 and no correlation coefficient smaller than .627. In the correlations with the isokinetic peak powers, coefficients for MRTD and MVS decreased as the isokinetic velocity increased, with few exceptions. For example, in PF the MRTD coefficients decreased from .871 to .795. In DF, power output at 30 deg/sec correlated better with MVS (r = .943) than with MRTD (r = .857). In PF, these coefficients were .858 and .871. In DF, power output at the nominal 240 deg/sec velocity correlated better with MRTD (r = .829) than did MVS (r = .752). In PF, these coefficients were .795 and .627.

Discussion

This study demonstrates that (a) both young and old healthy adults need on the order of 200 to 300 msec to develop from rest even modest levels of ankle torque; that (b) healthy old adults can require substantially longer than young adults to develop moderate to large ankle joint torques; and that (c) healthy old, in contrast to young adults,

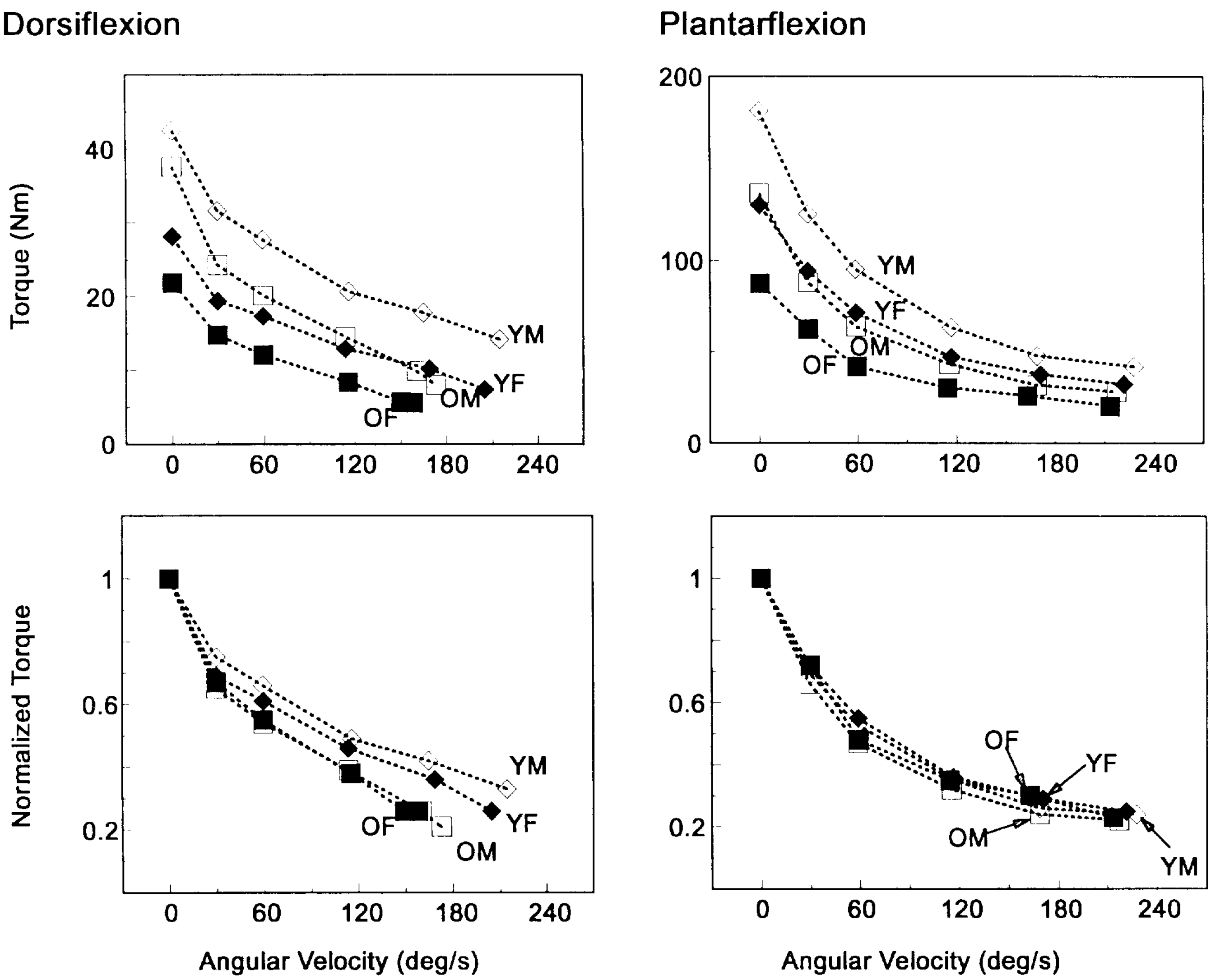

Figure 2. Mean absolute and normalized torque-angular velocity histories in isokinetic dorsiflexion and plantarflexion. Measured rather than nominal angular velocities are shown.

Table 3. Maximum Torques (Nm) and Normalized Torques for Each of the Subject Groups at the Nominal Isokinetic Velocities

Direction	Group	30 deg/sec	60 deg/sec	120 deg/sec	180 deg/sec	240 deg/sec
DF	YF	24 (4)*	20 (4)	14 (3)	10 (3)†	8 (2)†
	OF	15 (3)	12 (2)	8 (2)	6 (1)†	6 (1)†
	YM	32 (6)	28 (5)	21 (4)	17 (5)	14 (5)
	OM	19 (4)	17 (4)	13 (3)	10 (4)	7 (2)
PF	YF	85 (27)	62 (19)	42 (16)	27 (10)	26 (6)
	OF	60 (15)	42 (16)	27 (11)	23 (10)	17 (12)
	YM	124 (32)	90 (30)	61 (21)	47 (18)	39 (16)
	OM	94 (27)	71 (27)	46 (17)	36 (18)	32 (15)
Norm DF	YF	0.69 (0.08)	0.61 (0.09)	0.46 (0.08)		
	OF	0.68 (0.07)	0.55 (0.08)	0.38 (0.07)		
	YM	0.75 (0.06)	0.66 (0.07)	0.49 (0.06)		
	OM	0.65 (0.06)	0.54 (0.04)	0.39 (0.05)		
Norm PF	YF	0.72 (0.13)	0.55 (0.11)	0.36 (0.09)		
	OF	0.72 (0.14)	0.48 (0.18)	0.35 (0.11)		
	YM	0.69 (0.10)	0.53 (0.13)	0.35 (0.11)		
	OM	0.66 (0.16)	0.47 (0.18)	0.32 (0.10)		

Notes: By repeated measures ANOVA of age, gender and angular velocity effects:
Normalized torques differ with velocities, $p < .0001$.
Normalized dorsiflexion torques differ with age, $p < .0001$.
There is a significant interaction of age × velocity with normalized dorsiflexion torques, $p < .02$.
**SD* in parentheses.
†OA were substantially slower than nominal at the 180 and 240 deg/sec nominal velocities. Because of this, the normalized torques were not statistically analyzed at those two nominal angular velocities.

do not develop even modest levels of ankle torque at high rates of ankle rotation.

Many of the age differences observed in the contraction dynamics were associated with a loss in maximum voluntary isometric strength (MVS). Indeed, the OA reached given percentages of MVS nearly as fast as the YA, and MVS and MRTD were well correlated, indicating that either one of these measures can be used to estimate the other. However, it is the absolute torque magnitudes, much more than the percent MVS levels reached in a given time, that determine abilities to respond appropriately in many time-critical situations.

The exception to the pattern of age declines in abilities to develop torque rapidly being proportional to MVS declines occurred in DF. The 36 and 25 (females and males at 120 deg/sec) mean percent loss with age in maximum isokinetic PF torque was similar to the 32 and 24% decline in PF MVS, and was relatively independent of velocity through 240 deg/sec. The normalized PF torque-velocity curves therefore had similar shape for YA and OA, in agreement with the findings of Fugl-Meyer et al. (9). In comparison, the percent loss in DF torque with age increased with contraction velocity, reaching approximately 43 and 38% at the 120 deg/sec velocity. This contrasts with the 21 and 14% losses in isometric MVS with age.

Age declines in rapid torque development abilities might result from changes in cognition and motivation, changes in muscle recruitment and activation factors (18), or adaptations of muscle contraction mechanics with age (19). Although some studies (20) have found that both young and old adults have difficulty in recruiting PF motor units, other studies have shown that old adults are capable of fully recruiting their motor unit populations during maximal voluntary isometric (21) and isokinetic (22) exertions. The ratio of fast-twitch to slow-twitch fiber volumes is known to decrease with age (23). This ratio has been found to correlate with high-speed isokinetic knee extension strength (24) and may partially underlie the age-related losses in normalized high-speed DF strength observed in the present study.

The absolute isometric MVS measured in this study were similar in value to those measured by Fugl-Meyer et al. (9) and Vandervoort and McComas (21). Variability of MVS and MRTD measures across repeated trials was less in DF than in PF. One practical implication of this is that if lower extremity strengths are to be characterized by only a single measure of ankle strength, DF may be preferred to PF because of its smaller variability.

The major finding of this study is that healthy old adults, compared to young adults, have marked declines in their abilities to develop ankle joint torques rapidly. The capacities of old adults, even healthy ones, to recover balance when it is perturbed or to carry out other time-critical actions that require moderate to substantial strengths may be considerably degraded by these declines.

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