

# Differential Increases in Average Isokinetic Power by Specific Muscle Groups of Older Women Due to Variations in Training and Testing

Joseph F. Signorile,<sup>1,3,4</sup> Michelle P. Carmel,<sup>2,3</sup> Sara J. Czaja,<sup>2,5</sup>  
Shihab S. Asfour,<sup>2</sup> Robert O. Morgan,<sup>8</sup> Tarek M. Khalil,<sup>2</sup> Fangchao Ma,<sup>4,6</sup>  
and Bernard A. Roos<sup>3,4,6,7</sup>

Departments of <sup>1</sup>Exercise and Sport Sciences and <sup>2</sup>Industrial Engineering, University of Miami, Coral Gables, Florida.

<sup>3</sup>Stein Gerontological Institute, Miami, Florida.

<sup>4</sup>Geriatric Research, Education, and Clinical Center, Veterans Affairs Medical Center, Miami, Florida.

Departments of <sup>5</sup>Psychiatry and Behavioral Sciences, <sup>6</sup>Medicine, and <sup>7</sup>Neurology,  
University of Miami School of Medicine, Florida.

<sup>8</sup>Department of Medicine, Section of Health Services Research, Baylor College of Medicine, Houston, Texas.

**Background.** As a person ages, leg speed and power decrease. These changes are associated with increased falls and reduced gait speed. It has been shown that upper leg training in younger persons results in increased strength and power at the specific speed at which resistance training is applied, although there are only limited data concerning speed-specific training effects on lower leg activity. However, because both upper and lower leg speed and power influence gait and balance, it is important to determine the training speeds that selectively improve these variables in older persons.

**Methods.** No studies have examined selective speed-specific changes in performance for the upper and lower leg muscles in older individuals. Therefore, we compared shifts in the power-velocity relationship after high-speed (HS) and low-speed (LS) isokinetic training of knee extensors (KE) and flexors (KF), dorsiflexors (DF), and plantar flexors (PF) in community-dwelling women (ages 61 to 75). Subjects were randomly assigned to a HS training, LS training, or control (C) group. Training occurred three times a week for 12 weeks. HS training occurred at 4.73 rad·s<sup>-1</sup> (knee) and 3.14 rad·s<sup>-1</sup> (ankle); LS training for both joint actions was at 1.05 rad·s<sup>-1</sup>.

**Results.** HS training improved KE power at intermediate (3.14 rad·s<sup>-1</sup>;  $p = .0007$ ) and high (5.24 rad·s<sup>-1</sup>;  $p = .0004$ ) testing speeds. Neither the HS nor LS group showed any change in KF as a result of the training. Both LS and HS training improved DF power at all testing speeds; however, PF power improved only with LS training and only at 1.05 rad·s<sup>-1</sup> ( $p = .0132$ ) and 3.14 rad·s<sup>-1</sup> ( $p = .0310$ ).

**Conclusions.** Our results suggest that, in older women, lower leg training should occur at lower training speeds than upper leg training. Additionally, attention to differential speed-specific training of knee and ankle actions could improve power production, mobility, balance, and other functional measures in older persons.

STRENGTH and power are two distinct functional properties of intact skeletal muscle. Strength can be defined as the maximal force a muscle can produce at a specific velocity (movement speed in a specific direction) (1). Muscle power (or work rate) is the product of the force produced and the movement velocity (2). Reduced muscular power and movement velocity are associated with an increased probability of falls (3,4) and a reduction in the ability to perform activities of daily living (ADLs) in older individuals (5,6). In addition, a strong relationship has been reported between measures of leg strength and gait speed in frailer individuals (7,8). This relationship is especially important because low gait speed has been linked to reduced ADL independence (7,9,10), higher levels of self-reported disability (11), and the likelihood of fall-related hip fractures (12,13).

The need to address both velocity and strength in the development of power has long been recognized (14). Perfor-

mance-based studies have examined the relationship among speed, strength, and power (15) and have addressed the theory that strength gains are specific to the speed at which training is provided (16). A number of exercise studies have shown varying degrees of speed-specific improvement in power and strength when training is performed at different contractile speeds in healthy young adults and athletes. Most of these studies found that the greatest strength and power improvements occurred at or near the velocity at which training was provided (17-19). To date, however, there have been no reports of speed-specific training in older persons.

Studies examining speed-specific changes in muscle performance have focused on knee extension (19). There is only limited information on speed-specific training adaptations (20,21) in the dorsiflexors (22) and knee flexors (21), and no studies have examined speed specificity in the plantar flexors. Our study was based on the hypothesis that dif-

ferential speed-specific changes would occur during upper and lower leg training due to differences in muscle fiber type distribution (22,23), functional anatomy (24), maximum movement speed (25), and inherent contractile properties (26). It should also be noted that each of these factors changes with aging (23,27-29) and training (26,30-33). We compared the effects of high-speed versus low-speed isokinetic training on speed-specific changes in isokinetic power of the knee (extension, flexion) and ankle (dorsiflexion, plantar flexion) in healthy older women.

## METHODS

### Subjects

Twenty-eight healthy, independent-living women, ages 61 to 75, were recruited from the Miami-Dade metropolitan area. Four subjects left the study for personal reasons unrelated to the study. No subject had performed any resistance-training activities in the past 3 years. All subjects were fully informed of the procedures and signed an informed consent before beginning the study. All procedures were approved by the University of Miami Subcommittee for the Use and Protection of Human Subjects.

### Experimental Design

Before beginning the training program, subjects were tested isokinetically at 3.14 rad·s<sup>-1</sup> using a Biodex dynamometer (Biodex Corporation, Shirley, NY). The test for each joint was preceded by a five-repetition warm-up set using progressively more intense repetitions ranging from a perceived exertion of 50% to a maximum effort. The purpose of this warm-up set was to familiarize the subject with the feeling of isokinetic testing and to provide a movement-specific warm-up for the muscles to be tested. Following the warm-up, a 1-minute recovery was provided. The test set consisted of three maximal efforts. The peak torque value for knee extension of the right leg was used to match the subjects. After this process was completed, matched subjects were randomly assigned to one of three groups: a high-speed (HS) training group, a low-speed (LS) training group, or a control (C) group, using a random numbers table. Of the four subjects who left the study, one was from the HS group, one was from the C group, and two were from the LS group. The characteristics of each group are presented in Table 1. After assignment to groups and before training, the performance of subjects' knees and ankles was tested to establish their average power (AP) values at 1.05 rad·s<sup>-1</sup>, 3.14 rad·s<sup>-1</sup>, and 5.24 rad·s<sup>-1</sup>. After completion of the 12-week training program, subjects were again tested to establish the impact of the individual protocols on these variables. The

same technician performed all tests and was blinded concerning the LS, HS, or C group assignment.

### Isokinetic Testing

A Biodex isokinetic dynamometer (Biodex Corporation, Shirley, NY) was used for testing the AP of the right leg. Settings were adjusted to provide optimal mechanical advantage for each subject, and these settings were recorded and used for both baseline and post-training measures. Each subject was familiarized with the testing protocol and underwent three practice trials before the actual testing. Subjects were given two warm-up repetitions (50% and 75% perceived effort) and a short recovery before the testing set. The technician gave verbal encouragement throughout the testing session. The muscle actions (knee extension and flexion, ankle dorsiflexion, and plantar flexion) and testing speeds (1.05 rad·s<sup>-1</sup>, 3.14 rad·s<sup>-1</sup>, and 5.24 rad·s<sup>-1</sup>) were randomly assigned to each subject, and the testing sequence for that subject was held constant for the baseline and post-training sessions.

### Training

Both the HS and LS training groups trained three times a week for 12 weeks. All training was performed on the Biodex dynamometer under isokinetic conditions. The training speeds for each functional movement and the number of repetitions per training set for each group are shown in Table 2. A minimum of 2 minutes rest was provided between sets and 5 minutes between exercises. Knee extension and flexion were performed as reciprocal movements in one set and ankle plantar flexion and dorsiflexion as reciprocal movements during the other. The number of repetitions necessary to equilibrate total work at each speed was computed using data collected earlier on 104 older individuals, 62 to 78 years of age (J.F. Signorile, unpublished data, 1995). The C group performed a series of 10 active assisted stretches using a FlexMate stretching rope (Promise Enterprises, Jackson, MS). The stretches were designed to target all major muscle groups including the knee extensors, knee flexors, dorsiflexors, plantar flexors, shoulder adductors, shoulder abductors, shoulder flexors, shoulder extensors, elbow flexors, and elbow extensors.

### Statistical Analysis

All data were explored with descriptive statistics. Separate repeated measures analysis of variance (ANOVA) for knee extension, knee flexion, dorsiflexion, and plantar flexion was performed for the AP measured at each testing speed (1.05 rad·s<sup>-1</sup>, 3.14 rad·s<sup>-1</sup>, and 5.24 rad·s<sup>-1</sup>), with group (i.e., C, HS, or LS) as the between-factor and time

Table 1. Characteristics of Subjects

Training Group	n	Age (y)	Weight (kg)	Height (cm)
HS	9	68.37 ± 1.42	65.19 ± 4.33	160.61 ± 1.10
LS	8	68.76 ± 1.62	68.38 ± 3.86	163.13 ± 1.47
C	7	69.01 ± 1.75	68.17 ± 3.65	154.93 ± 1.30

Notes: Values are means ± SE. HS = high-speed training group; LS = low-speed training group; C = control group.

Table 2. Training Protocols

Joint	Movement	Group	Speed (rad·s <sup>-1</sup> )	Repetitions
Knee	Extension/flexion	HS	4.73	10
		LS	1.05	6
Ankle	Plantar flexion/dorsiflexion	HS	3.14	8
		LS	1.05	6

Note: HS = high speed; LS = low speed.

(i.e., baseline vs post-training) as the within-factor. All main effects and interaction effects were examined. If the group  $\times$  time interaction was significant, post hoc Bonferroni tests of group differences across changes between baseline and post-training were performed. Because of the homogeneity of age, gender, and race/ethnicity among the C, HS, and LS groups, these covariates were not included in the repeated measures ANOVA. An accepted probability level of  $p \leq .05$  was used for all statistical tests.

All analyses were performed using the SAS System for Windows (release 8.02). The "PROC MIXED" procedure was used for the repeated measures analysis of variance (SAS Institute, Cary, NC).

## RESULTS

The compliance rate for the HS training group was 95.4%. The LS group attended 93.2% of their sessions. The C group compliance rate was 95.8%.

### Knee Extension

Figure 1 shows the baseline and post-training power-isokinetic speed curves for each training condition (HS, LS, and C, respectively). The repeated measures ANOVA revealed significant changes across time at each testing speed. However, the Bonferroni test indicated that no significant improvements were made by any treatment group at 1.05  $\text{rad}\cdot\text{s}^{-1}$ . At 3.14  $\text{rad}\cdot\text{s}^{-1}$  and 5.24  $\text{rad}\cdot\text{s}^{-1}$ , a significant treatment  $\times$  time interaction was detected. The Bonferroni test revealed that only the HS group made a significant improvement in AP (mean  $\pm$  SE) (3.14  $\text{rad}\cdot\text{s}^{-1}$ ,  $\Delta\text{AP} = 25.96 \pm 5.06$  W,  $p = .0007$ ; 5.24  $\text{rad}\cdot\text{s}^{-1}$ ,  $\Delta\text{AP} = 32.49 \pm 6.34$  W,  $p = .0004$ ).

### Knee Flexion

Baseline and post-training isokinetic AP curves during knee flexion are shown in Figure 2. Repeated measures ANOVA on knee flexion data at 1.05  $\text{rad}\cdot\text{s}^{-1}$ , 3.14  $\text{rad}\cdot\text{s}^{-1}$ , and 5.24  $\text{rad}\cdot\text{s}^{-1}$  revealed no significant time  $\times$  treatment interactions. In addition, no significant improvements were made by any treatment group across time.

### Ankle Dorsiflexion

Figure 3 shows the baseline and post-training AP curves for ankle dorsiflexion. The repeated measures ANOVA revealed no significant treatment  $\times$  time interactions; however, a significant time effect was detected at all testing speeds ( $p = .0001$ ). The Bonferroni test showed significant improvements by both the LS and HS groups at 1.05  $\text{rad}\cdot\text{s}^{-1}$  (HS  $\Delta\text{AP} = 2.51 \pm 0.55$  W,  $p = .0036$ ; LS  $\Delta\text{AP} = 3.50 \pm 0.36$  W,  $p = .0003$ ), 3.14  $\text{rad}\cdot\text{s}^{-1}$  (HS  $\Delta\text{AP} = 6.31 \pm 1.06$  W,  $p = .0001$ ; LS  $\Delta\text{AP} = 6.66 \pm 1.01$  W,  $p = .0001$ ), and 5.24  $\text{rad}\cdot\text{s}^{-1}$  (HS  $\Delta\text{AP} = 5.65 \pm 0.82$  W,  $p = .0001$ ; LS  $\Delta\text{AP} = 7.60 \pm 0.65$  W,  $p = .0001$ ). No significant changes were seen in the C group at any testing speed.

### Ankle Plantar Flexion

Baseline and post-training isokinetic AP during plantar flexion for the HS, LS, and C groups, respectively, are presented in Figure 4. The repeated measures ANOVA re-

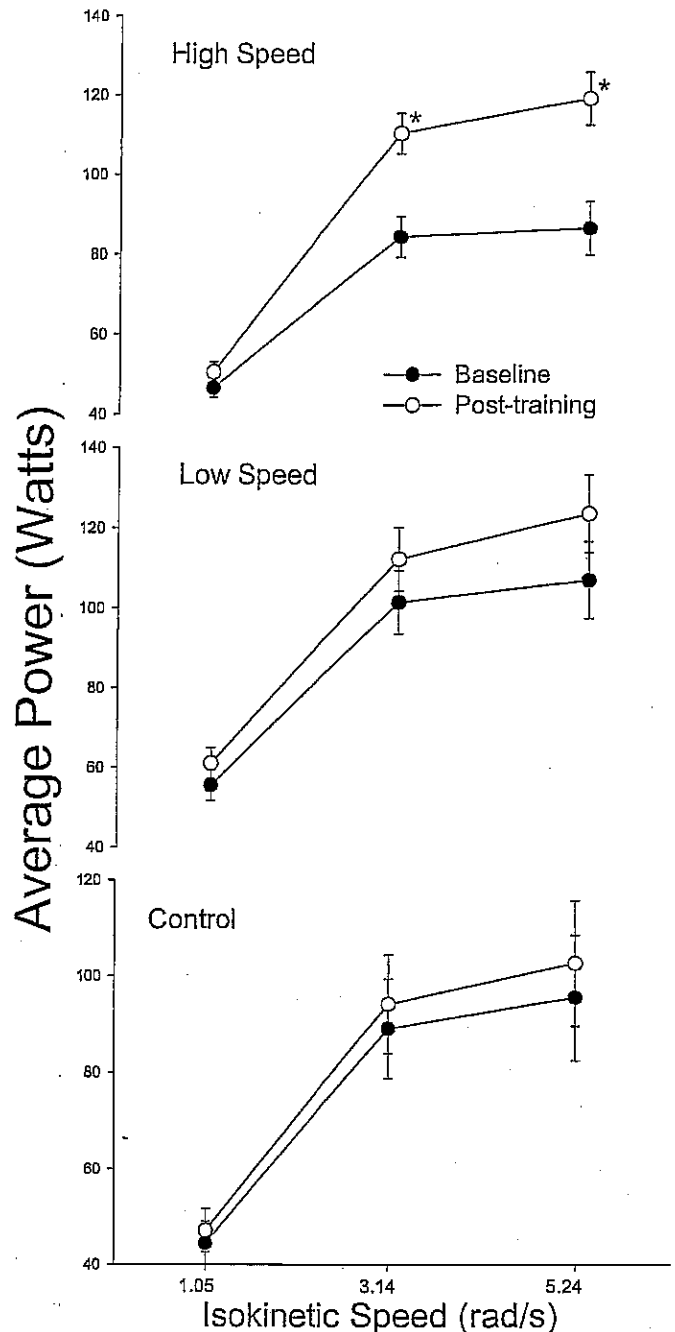


Figure 1. Average power curves for the knee extensors. \*Significant improvement between baseline and post-training values. Symbols represent mean  $\pm$  SE. Filled circles represent baseline values, while open circles represent post-training values.

vealed significant time effects at both 1.05  $\text{rad}\cdot\text{s}^{-1}$  and 3.14  $\text{rad}\cdot\text{s}^{-1}$ . The Bonferroni test showed that the power improvements were exclusive to the LS group ( $\Delta\text{AP}$  at 1.05  $\text{rad}\cdot\text{s}^{-1} = 9.12 \pm 2.63$  W,  $p = .0132$ ;  $\Delta\text{AP}$  at 3.14  $\text{rad}\cdot\text{s}^{-1} = 12.47 \pm 3.53$  W,  $p = .0310$ ).

## DISCUSSION

The major finding of this study was that LS and HS training differentially improved upper and lower leg AP, with

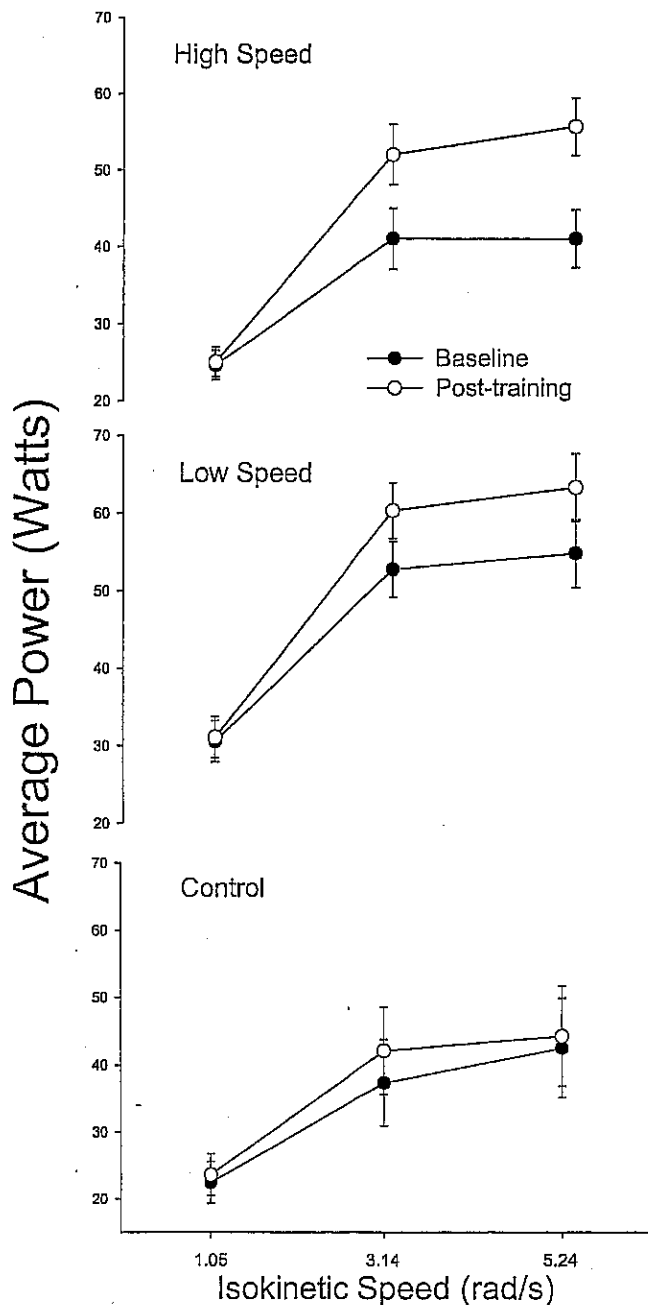


Figure 2. Average power curves for the knee flexors. Symbols represent mean  $\pm$  SE. Filled circles represent baseline values, while open circles represent post-training values.

LS training favoring the lower leg and HS training favoring the upper leg. The lack of significant strength improvements by the C group was expected because little or no external loading occurred during the active-assisted stretching protocol. Knowledge of optimal training speeds for the upper and lower leg should improve preventive exercise prescription for older persons.

#### Knee Extension

Our results, showing AP improvements ( $\Delta$ AP) at the higher testing speeds by the HS group, are similar to those

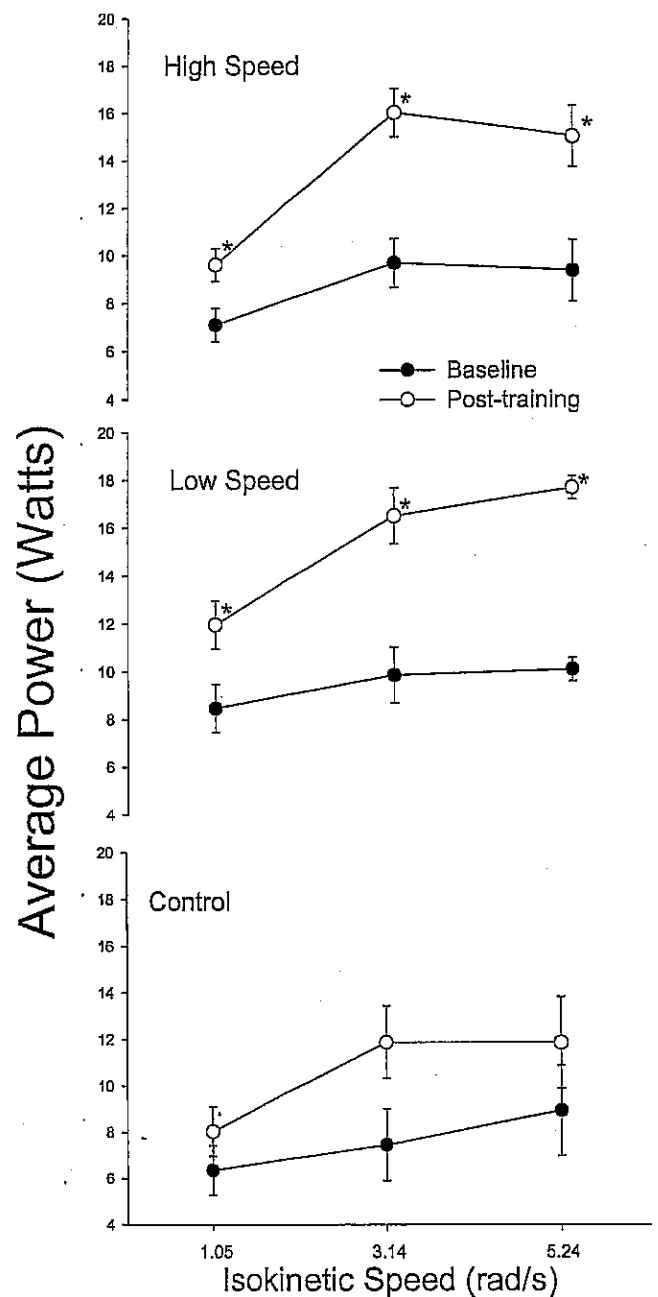


Figure 3. Average power curves for the ankle dorsiflexors. \*Significant improvement between baseline and post-training values. Symbols represent mean  $\pm$  SE. Filled circles represent baseline values, while open circles represent post-training values.

reported by Kanehisa and Miyashita (18), the only other study to evaluate speed-specific changes in isokinetic power as a result of isokinetic training. However, in contrast to their results, which indicated that the low-speed training group ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ) produced significant improvements at all speeds tested ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ,  $3.14 \text{ rad}\cdot\text{s}^{-1}$ , and  $5.24 \text{ rad}\cdot\text{s}^{-1}$ ), our LS group showed no improvements at any testing speed. One explanation for this difference may be that Kanehisa and Miyashita (18) examined young male subjects while we studied older women. Because strength (34), rate of torque

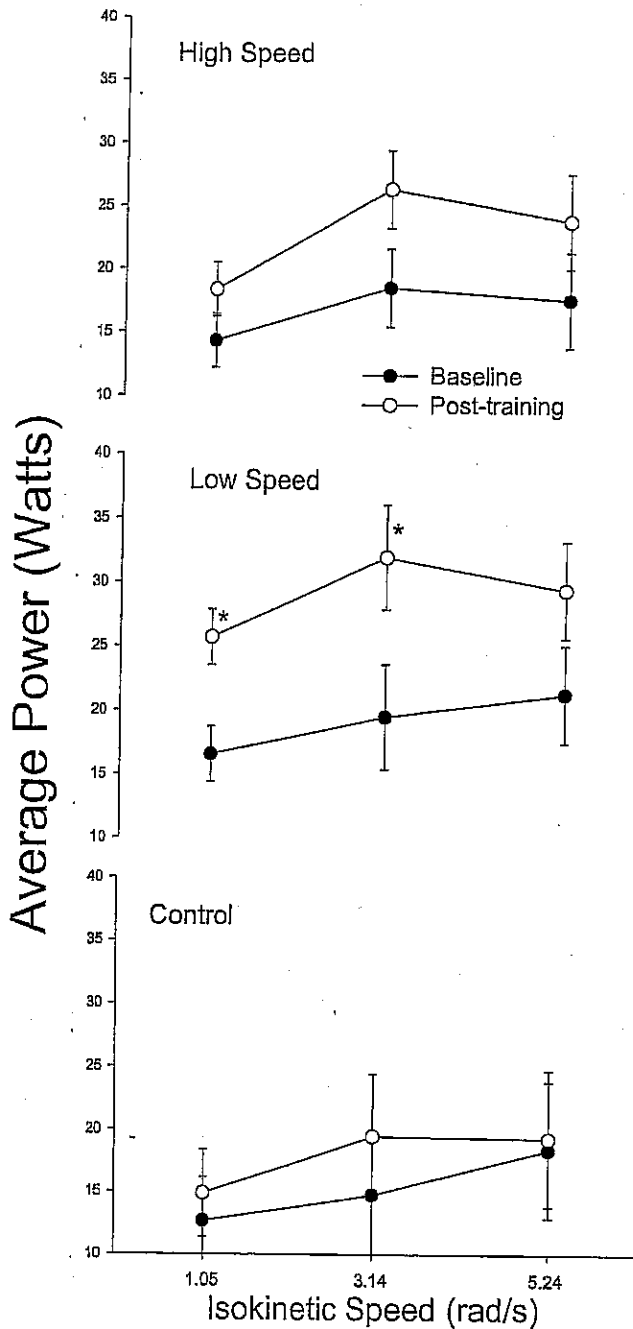


Figure 4. Average power curves for the ankle plantar flexors. \*Significant improvement between baseline and post-training values. Symbols represent mean  $\pm$  SE. Filled circles represent baseline values, while open circles represent post-training values.

production (35), and muscle cross-sectional area (especially of the type II fibers) (27) are affected by age and gender, baseline values in our group would be expected to be lower than those produced in the group studied by Kanehisa and Miyashita (18). Our results suggest a greater need to incorporate faster training speeds into resistance training programs designed to target upper leg function in older individuals. Our knee extension AP findings are similar to the knee torque changes reported by Coyle and colleagues (19), who stated that their HS training group ( $5.24 \text{ rad}\cdot\text{s}^{-1}$ ) showed

significantly greater improvements than a placebo group at intermediate ( $3.14 \text{ rad}\cdot\text{s}^{-1}$ ) and high ( $5.24 \text{ rad}\cdot\text{s}^{-1}$ ), but not at low ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ), testing speeds, while their LS group improved only at  $1.05 \text{ rad}\cdot\text{s}^{-1}$ . In contrast, our LS group showed no power improvements at any test speed. The lack of improvement by our LS group may have been the result of the lower training speed employed during our study, the age of the participants, or the fact that Coyle and colleagues (19) examined torque rather than power, which has a speed component built into its computation.

Another study measuring torque changes over 4 weeks of isokinetic training of the knee extensors at either  $1.68 \text{ rad}\cdot\text{s}^{-1}$  or  $4.19 \text{ rad}\cdot\text{s}^{-1}$  in young men produced results similar to those seen in our HS group, with improvements at  $2.51 \text{ rad}\cdot\text{s}^{-1}$ ,  $3.35 \text{ rad}\cdot\text{s}^{-1}$ , and  $4.19 \text{ rad}\cdot\text{s}^{-1}$  (20). However, unlike the LS group in our study, subjects in the study by Caiozzo and colleagues (20), who trained at  $1.68 \text{ rad}\cdot\text{s}^{-1}$ , produced significant improvements at velocities of 0, 0.84, 1.68, 2.51, 3.35, and  $4.19 \text{ rad}\cdot\text{s}^{-1}$ . Once again, differences in age, gender, and the dependent variable (torque vs power) may all have been confounding factors in the comparison.

Moffroid and Whipple (17) also examined the effects of HS and LS training on knee extensor torque production. Their HS group exercised at  $1.89 \text{ rad}\cdot\text{s}^{-1}$ , and their LS group trained at  $0.63 \text{ rad}\cdot\text{s}^{-1}$ . The LS subjects made significantly greater increases in torque production at low testing speeds ( $0.63 \text{ rad}\cdot\text{s}^{-1}$ ,  $0.31 \text{ rad}\cdot\text{s}^{-1}$ ) than at the higher testing speeds ( $0.95$ ,  $1.26$ ,  $1.58$ ,  $1.89 \text{ rad}\cdot\text{s}^{-1}$ ), while the HS group produced significant increases at all test speeds. The results of their HS training group are similar to our power results, showing improvements across the entire speed spectrum. However, they differ dramatically from those seen in our LS group, where we recorded no significant improvements in power. Once again, differences in gender, age, and the outcome variable (torque vs power) are likely reasons. In addition, the lower training and testing speeds employed by Moffroid and Whipple (17) may have produced a different training stimulus from those used in our study.

#### Knee Flexion

Of the studies examining the speed-specific impact of isokinetic resistance training on leg power and torque, only the study by Housh and Housh (21) reported knee flexion data. While we found no significant increases in AP by any of the groups tested (HS, LS, or C), they reported significant increases in peak torque at all testing speeds ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ,  $2.10 \text{ rad}\cdot\text{s}^{-1}$ ,  $3.14 \text{ rad}\cdot\text{s}^{-1}$ ,  $4.20 \text{ rad}\cdot\text{s}^{-1}$ , and  $5.24 \text{ rad}\cdot\text{s}^{-1}$ ) as a result of training at  $2.10 \text{ rad}\cdot\text{s}^{-1}$ . It should be noted that the post hoc analysis did show a trend toward speed-specific increases in power for the HS group at both  $3.14 \text{ rad}\cdot\text{s}^{-1}$  ( $\Delta\text{AP} = 10.97 \text{ W}$ ;  $p = .1138$ ) and  $5.24 \text{ rad}\cdot\text{s}^{-1}$  ( $\Delta\text{AP} = 14.62 \text{ W}$ ;  $p = .1677$ ) even after the Bonferroni adjustment. Methodological differences between these two studies such as gender, age, and training speeds may, once again, explain the divergent results between the two studies. Additionally, because knee extension and flexion were trained as reciprocating movements during the same training set, the subjects may have placed greater concentration on the more dominant knee extensors than the knee flexors.

### *Ankle Dorsiflexion*

Only one other study has examined speed-specific training of the ankle dorsiflexors. In that study, Behm and Sale (22) trained eight men and eight women, aged  $20.9 \pm 0.5$  years, 3 days a week for 16 weeks. Their subjects trained using either high-speed isokinetic training at  $5.23 \text{ rad}\cdot\text{s}^{-1}$  or isometric training. Under both conditions, the subjects attempted to contract the muscle as strongly and rapidly as possible. Regardless of the training modality, subjects showed significant increases in peak torque at 1.04, 1.55, 3.02, 4.19, and  $5.23 \text{ rad}\cdot\text{s}^{-1}$ , with the greatest improvements at  $5.23 \text{ rad}\cdot\text{s}^{-1}$ . These torque results are similar to the training results seen for dorsiflexion power in our study, where both the HS and LS groups showed significant increases at all testing speeds.

### *Ankle Plantar Flexion*

To the best of our knowledge, no other studies have examined the impact of varied training speeds on power-velocity or force-velocity relationships during plantar flexion. Our data showing significant improvement by the LS group at  $1.05 \text{ rad}\cdot\text{s}^{-1}$  support the concept of speed specificity. The transfer of strength improvement to the higher testing speed of  $3.14 \text{ rad}\cdot\text{s}^{-1}$  reflects the results reported by Housh and Housh (21) for a number of other muscle groups. The difference between these results and those for other leg actions may have been dictated by a number of factors. Alway and colleagues (36) have noted that the triceps surae group has a lower rate of tension development than that of other muscles with similar fiber type distributions due to the compliance of the Achilles tendon. In addition, the gastrocnemius is a biarticular muscle, and its slackened condition when the knee is bent reduces its effectiveness as a plantar flexor (25,37). Because our training and testing utilized a knee angle of  $135^\circ$ , the contribution of the gastrocnemius muscle was reduced, and greater reliance was placed on the slower-contracting soleus muscle. Therefore, the HS group may not have been able to produce the necessary movement speed to develop sufficient torque to elicit a training effect.

### *Comparisons Among Muscle Groups*

Although the knee extension and knee flexion results for the HS and LS groups do mirror each other, the differences between the groups were significant only during knee extension. A number of researchers have reported that the knee flexors are more receptive to intermediate speed training than the knee extensors (38–40). One explanation is that the hamstrings have a higher proportion of type II fibers than the quadriceps group and can produce higher tension (41). Therefore, the HS stimulus that provided sufficient overload for the quadriceps group may not have been adequate for the hamstrings. The reduced training effect could have lessened the differences between the HS and LS groups.

The pattern of change in the ankle dorsiflexors differs from that at the knee or during ankle plantar flexion. The dorsiflexor improvements at all testing speeds may indicate that the small muscle mass and consequential greater tension per cross-sectional area of the dorsiflexors resulted in a greater training stimulus. Also, the ankle dorsiflexors have a far lower load-bearing requirement than the plantar flexors in normal everyday activities. In concert, these factors

would put the dorsiflexors at a lower initial level of performance and consequently at a steeper portion of the training curve than the plantar flexors.

The positive impact made by our HS training protocol on dorsiflexor performance at lower test speeds has been reported in studies examining other muscle groups (19,42). The significant improvements in dorsiflexion by the LS group at all speeds of testing are also not without precedent. Behm and Sale (22) noted that isometric training, employing high rates of tension development, produced strength gains similar to isokinetic training at high speeds across high, intermediate, and low testing speeds. A comparison of the shapes of the HS and LS dorsiflexion test curves with analogous curves from the knee extensors and flexors seems to demonstrate that the dorsiflexors cannot produce the high movement speeds seen during knee extension and flexion. The inability of the dorsiflexors to produce movement speeds comparable to the knee extensors and flexors may be attributable to their inherent contractile speed, smaller mass, or shorter functional lever system. In addition, the inability to produce substantially higher power values at higher isokinetic speeds and the continual rise in the test curve at  $5.24 \text{ rad}\cdot\text{s}^{-1}$  for the LS versus HS condition seem to argue for the use of lower training speeds for this muscle group.

The unique results seen during plantar flexion, where the only significant improvement was made by the LS group at  $1.05 \text{ rad}\cdot\text{s}^{-1}$ , may also be attributable to the training and testing speeds selected for use during this study. Detailed analysis of the test curves, using only the areas where the set isokinetic speed was attained, revealed that the HS group was able to meet the set speed only for short time periods, and the low torque values they produced indicate that they were training toward the top end of their speed spectrum (data not shown). Thus, the resistance component of their training was reduced, and the training effect was lessened. In contrast, the LS group, due to the lower speed setting of the dynamometer, received greater resistance and a more effective training stimulus throughout the range of motion. This explanation is strengthened by the comparative shapes of the test curves for both groups, which, unlike the sharply up-sloping curves seen for knee extension and flexion, showed a notable plateau or decline in power at  $5.24 \text{ rad}\cdot\text{s}^{-1}$ . These pattern differences suggest that our older women could not produce the movement speed necessary to perform the plantar flexion-optimally during training and testing. Moreover, as was the case with the dorsiflexors, our results suggest that the HS training speed ( $3.14 \text{ rad}\cdot\text{s}^{-1}$ ) was too high. Further studies are necessary to ascertain the optimal training speed for this muscle group.

In summary, our results for the knee extensors confirm the importance of HS training in shifting the power-velocity relationship and also indicate that a transfer of the training effect to somewhat lower (intermediate) speeds of movement can be expected for the knee extensors. With respect to power improvements in the lower leg (ankle dorsiflexors and plantar flexors), our data suggest that low to intermediate training speeds are better than high speeds.

### *Significance for Independence and Fall Prevention*

Skelton and colleagues (43,44) have reported that leg extensor power declines approximately 3.5% per year between

the ages of 60 and 89, and that power is directly related to ADL functions such as stair climbing and lifting a shopping bag. Bassey and colleagues (6) reported significant correlations between leg extensor power and daily activities such as stair climbing, rising from a chair, and walking without a walker. In community-dwelling older women, Foldvari and colleagues (5) reported that, among all physiological factors tested, leg power showed the highest correlation ( $r = -.47$ ;  $p < .0001$ ) with self-reported functional status. In addition, the association between gait speed and independence is well established (7,9-11). Dutta and colleagues (45) noted that many of the activities of everyday living, such as stopping abruptly to avoid a car at a crosswalk, recovering from a stumble, or grabbing a handrail, depend on speed, and, therefore, speed must be adequately addressed for an exercise program to have positive effects on ADL performance.

When fall prevention is considered, power and contractile speed again present as important modifying factors. Failure to recognize this fact may set too low a standard for prescribing preventive exercises. In an examination of 34 nursing home residents classified as fallers and nonfallers, Whipple and colleagues (3) found that the strength and power of the knee extensors and flexors, as well as the ankle dorsiflexors and plantar flexors, were lower in fallers than in nonfallers. A biomechanical analysis by Grabiner and colleagues (4) found that lower extremity muscular power and the ability to restore control of the flexing trunk were the two major determining factors. Greenspan and colleagues (46) reported that most hip fractures occur during falls to the back and side, while Cummings and Nevitt (12) and Smeesters and colleagues (13) independently showed that gait speed influences the direction of falls, with higher gait speeds dictating forward falls.

A number of studies have shown that both strength and power can be improved in older individuals using standard resistance training protocols (33,44,47-51). However, when strength, power, and movement speed are considered in relation to fall prevention and the preservation of independence, there is little doubt that increasing power across the velocity spectrum would have significant benefits in an older population. Our finding, that the upper and lower leg may respond differently to HS and LS training, opens the way for joint-specific exercise prescriptions targeting speed and power in older persons. These prescriptions should provide more effective training to improve ADL performance and prevent falls in older individuals.

#### ACKNOWLEDGMENTS

We are grateful for support from the Teaching Nursing Home program, funded by the State of Florida Agency for Health Care Administration, during the data analysis and manuscript preparation portions of this project. In addition, we thank the University of Miami students who helped with data collection and training, including Ms. Laura Myerburg, Ms. Rachael Epstein, and Mr. Brandon Feldman.

Address correspondence to Dr. Joseph F. Signorile, Stein Gerontological Institute, 5200 NE Second Ave., Miami, FL 33137. E-mail: jsignorile@miami.edu

#### REFERENCES

1. Knuttgen HG, Kraemer WJ. Terminology and measurement in exercise performance. *J Appl Sports Sci Res.* 1987;1:1-10.
2. Newton RU, Kraemer WJ. Developing explosive muscular power: implications for mixed methods training strategy. *Natl Strength Conditioning Assoc J.* 1994;16:20-31.
3. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. *J Am Geriatr Soc.* 1987;35:13-20.
4. Grabiner MD, Koh TJ, Lundin TM, Jahnigen DW. Kinematics of recovery from a stumble. *J Gerontol Med Sci.* 1993;48:M97-M102.
5. Foldvari M, Clark M, Laviolette LC, et al. Association of muscle power with functional status in community-dwelling elderly women. *J Gerontol Med Sci.* 2000;55A:M192-M199.
6. Bassey EJ, Fiatarone MA, O'Neill EF, Kelly M, Evans WJ, Lipsitz LA. Leg extensor power and functional performance in very old men and women. *Clin Sci (Colch).* 1992;82(3):321-327.
7. Gibbs J, Hughes S, Dunlop D, Singer R, Chang RW. Predictors of change in walking velocity in older adults. *J Am Geriatr Soc.* 1996;44:126-132.
8. Buchner D, Larson EB, Wagner EH, Koepsell TD, de Lateur BJ. Evidence for a non-linear relationship between leg strength and gait speed. *Age Ageing.* 1996;25(5):386-391.
9. Friedman PJ, Richmond DE, Baskett JJ. A prospective trial of serial gait speed as a measure of rehabilitation in the elderly. *Age Ageing.* 1988;17(4):227-235.
10. Judge JO, Schechtman K, Cress E. The relationship between physical performance measures and independence in instrumental activities of daily living. The FICSIT Group. Frailty and Injury: Cooperative Studies of Intervention Trials. *J Am Geriatr Soc.* 1996;44:1332-1341.
11. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol Med Sci.* 1994;49:M85-M94.
12. Cummings SR, Nevitt MC. A hypothesis: the causes of hip fractures. *J Gerontol Med Sci.* 1989;44:M107-M111.
13. Smeesters C, Hayes WC, McMahon TA. Disturbance type and gait speed affect fall direction and impact location. *J Biomech.* 2001;34(3):309-317.
14. Kraemer WJ, Fleck SJ, Evans WJ. Strength and power training: physiological mechanisms of adaptation. *Exerc Sport Sci Rev.* 1996;24:363-397.
15. Häkkinen K, Komi PV. Effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch-shortening cycle exercises. *Scand J Sports Sci.* 1985;7(2):65-76.
16. Bell GJ, Wenger HA. Physiological adaptations to velocity-controlled resistance training. *Sports Med.* 1992;13(4):234-244.
17. Moffroid M, Whipple RH. Specificity of speed of exercise. *Phys Ther.* 1970;50(12):1692-1700.
18. Kanehisa H, Miyashita M. Specificity of velocity in strength training. *Eur J Appl Physiol Occup Physiol.* 1983;52(1):104-106.
19. Coyle EF, Feiring DC, Rotkis TC, et al. Specificity of power improvements through slow and fast isokinetic training. *J Appl Physiol.* 1981;51:1437-1442.
20. Caiozzo VJ, Perrine JJ, Edgerton VR. Training-induced alterations of the in vivo force-velocity relationship of human muscles. *J Appl Physiol.* 1981;51:750-754.
21. Housh DJ, Housh TJ. The effects of unilateral velocity-specific concentric strength training. *J Orthop Sports Phys Ther.* 1993;17(5):252-256.
22. Behm DG, Sale DG. Intended rather than actual movement velocity determines velocity-specific training response. *J Appl Physiol.* 1993;74:359-368.
23. Häkkinen K, Newton RU, Gordon SE, et al. Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *J Gerontol Biol Sci.* 1998;53A:B415-B423.
24. Thompson CW, Floyd RT. *Manual of Structural Kinesiology.* 12th ed. St. Louis, MO: Mosby; 1994.
25. Tamaki H, Kitada K, Akamine T, Sakou T, Kurata H. Electromyogram patterns during plantarflexions at various angular velocities and knee angles in human triceps surae muscles. *Eur J Appl Physiol Occup Physiol.* 1997;75:1-6.
26. Alway SE, MacDougall JD, Sale DG, Sutton JR, McComas AJ. Functional and structural adaptations in skeletal muscle of trained athletes. *J Appl Physiol.* 1988;64:1114-1120.

27. Lexell J. Human aging, muscle mass, and fiber type composition. *J Gerontol Biol Sci Med Sci*. 1995;50A(Special Issue):11-16.
28. Larsson L, Li X, Frontera WR. Effects of aging on shortening velocity and myosin isoform composition in single human skeletal muscle cells. *Am J Physiol*. 1997;272:C638-C649.
29. Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R. Aging of skeletal muscle: a 12-yr longitudinal study. *J Appl Physiol*. 2000;88:1321-1326.
30. Häkkinen K. Neuromuscular and hormonal adaptations during strength and power training. *J Sports Med Phys Fitness*. 1989;29:9-26.
31. Staron RS, Malicky ES, Leonard MJ, Falkel JE, Hagerman FC, Dudley GA. Muscle hypertrophy and fast fiber type conversions in heavy resistance-trained women. *Eur J Appl Physiol Occup Physiol*. 1990;60:71-79.
32. Hunter SK, Thompson MW, Ruell PA, et al. Human skeletal sarcoplasmic reticulum Ca<sup>2+</sup> uptake and muscle function with aging and strength training. *J Appl Physiol*. 1999;86:1858-1865.
33. Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG, Evans WJ. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol*. 1988;64:1038-1044.
34. Frontera WR, Hughes VA, Lutz KJ, Evans WJ. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol*. 1991;71:644-650.
35. Behm DG, Sale DG. Voluntary and evoked muscle contractile characteristics in active men and women. *Can J Appl Physiol*. 1994;19:253-265.
36. Alway SE, MacDougall JD, Sale DG. Contractile adaptations in the human triceps surae after isometric exercise. *J Appl Physiol*. 1989;66:2725-2732.
37. Signorile JF, Applegate B, Duque M, Cole N, Zink A. Selective recruitment of the triceps surae muscles with changes in knee angle. *J Strength Cond Res*. In press.
38. Bell GJ, Petersen SR, Quinney HA, Wenger HA. Sequencing of endurance and high-velocity strength training. *Can J Sports Sci*. 1988;13:214-219.
39. Lesmes GR, Costill DL, Coyle EF, Fink WJ. Muscle strength and power changes during maximal isokinetic training. *Med Sci Sports*. 1978;10(4):266-269.
40. Petersen S, Miller G, Quinney HA, Wenger HA. The influence of high-velocity resistance training on aerobic power. *J Orthop Sports Phys Ther*. 1988;9:339-344.
41. Garrett WE Jr, Califf JC, Basset FH 3rd. Histochemical correlates of hamstring injuries. *Am J Sports Med*. 1984;12(2):98-103.
42. Dudley GA, Djamil R. Incompatibility of endurance- and strength-training modes of exercise. *J Appl Physiol*. 1985;59:1446-1451.
43. Young A, Skelton A. Applied physiology of strength and power in old age. *Int J Sports Med*. 1994;15(3):149-151.
44. Skelton DA, Young A, Greig CA, Malbut KE. Effects of resistance training on strength, power, and selected functional abilities of women aged 75 and older. *J Am Geriatr Soc*. 1995;43:1081-1087.
45. Dutta C, Hadley EC, Lexell J. Sarcopenia and physical performance in old age: overview. *Muscle Nerve*. 1997;5(Suppl):S5-S9.
46. Greenspan SL, Myers EJ, Maitland LA, Resnick NM, Hayes WC. Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. *JAMA*. 1994;271(2):128-133.
47. Fiatarone MA, Evans WJ. Exercise in the oldest old. *Top Geriatr Rehabil*. 1990;5(2):63-77.
48. Jozsi AC, Campbell WW, Joseph L, Davey SL, Evans WJ. Changes in power with resistance training in older and younger men and women. *J Gerontol Med Sci*. 1999;54A:M591-M596.
49. Tracy BL, Ivey FM, Hurlbut D, et al. Muscle quality. II. Effects of strength training in 65- to 75-yr-old men and women. *J Appl Physiol*. 1999;86:195-201.
50. Cohn SH, Vartsky D, Yasumura S, et al. Compartmental body composition based on total-body nitrogen, potassium, and calcium. *Am J Physiol*. 1980;239(6):E524-E530.
51. Novak LP. Aging, total body potassium, fat-free mass, and cell mass in males and females between ages 18 and 85 years. *J Gerontol*. 1972;27:438-443.

Received January 28, 2002

Accepted April 19, 2002

# Differential Increases in Average Isokinetic Power by Specific Muscle Groups of Older Women Due to Variations in Training and Testing

Joseph F. Signorile,<sup>1,3,4</sup> Michelle P. Carmel,<sup>2,3</sup> Sara J. Czaja,<sup>2,5</sup>  
Shihab S. Asfour,<sup>2</sup> Robert O. Morgan,<sup>8</sup> Tarek M. Khalil,<sup>2</sup> Fangchao Ma,<sup>4,6</sup>  
and Bernard A. Roos<sup>3,4,6,7</sup>

Departments of <sup>1</sup>Exercise and Sport Sciences and <sup>2</sup>Industrial Engineering, University of Miami, Coral Gables, Florida.

<sup>3</sup>Stein Gerontological Institute, Miami, Florida.

<sup>4</sup>Geriatric Research, Education, and Clinical Center, Veterans Affairs Medical Center, Miami, Florida.

Departments of <sup>5</sup>Psychiatry and Behavioral Sciences, <sup>6</sup>Medicine, and <sup>7</sup>Neurology,  
University of Miami School of Medicine, Florida.

<sup>8</sup>Department of Medicine, Section of Health Services Research, Baylor College of Medicine, Houston, Texas.

**Background.** As a person ages, leg speed and power decrease. These changes are associated with increased falls and reduced gait speed. It has been shown that upper leg training in younger persons results in increased strength and power at the specific speed at which resistance training is applied, although there are only limited data concerning speed-specific training effects on lower leg activity. However, because both upper and lower leg speed and power influence gait and balance, it is important to determine the training speeds that selectively improve these variables in older persons.

**Methods.** No studies have examined selective speed-specific changes in performance for the upper and lower leg muscles in older individuals. Therefore, we compared shifts in the power-velocity relationship after high-speed (HS) and low-speed (LS) isokinetic training of knee extensors (KE) and flexors (KF), dorsiflexors (DF), and plantar flexors (PF) in community-dwelling women (ages 61 to 75). Subjects were randomly assigned to a HS training, LS training, or control (C) group. Training occurred three times a week for 12 weeks. HS training occurred at 4.73 rad·s<sup>-1</sup> (knee) and 3.14 rad·s<sup>-1</sup> (ankle); LS training for both joint actions was at 1.05 rad·s<sup>-1</sup>.

**Results.** HS training improved KE power at intermediate (3.14 rad·s<sup>-1</sup>;  $p = .0007$ ) and high (5.24 rad·s<sup>-1</sup>;  $p = .0004$ ) testing speeds. Neither the HS nor LS group showed any change in KF as a result of the training. Both LS and HS training improved DF power at all testing speeds; however, PF power improved only with LS training and only at 1.05 rad·s<sup>-1</sup> ( $p = .0132$ ) and 3.14 rad·s<sup>-1</sup> ( $p = .0310$ ).

**Conclusions.** Our results suggest that, in older women, lower leg training should occur at lower training speeds than upper leg training. Additionally, attention to differential speed-specific training of knee and ankle actions could improve power production, mobility, balance, and other functional measures in older persons.

**S**TRENGTH and power are two distinct functional properties of intact skeletal muscle. Strength can be defined as the maximal force a muscle can produce at a specific velocity (movement speed in a specific direction) (1). Muscle power (or work rate) is the product of the force produced and the movement velocity (2). Reduced muscular power and movement velocity are associated with an increased probability of falls (3,4) and a reduction in the ability to perform activities of daily living (ADLs) in older individuals (5,6). In addition, a strong relationship has been reported between measures of leg strength and gait speed in frailer individuals (7,8). This relationship is especially important because low gait speed has been linked to reduced ADL independence (7,9,10), higher levels of self-reported disability (11), and the likelihood of fall-related hip fractures (12,13).

The need to address both velocity and strength in the development of power has long been recognized (14). Perfor-

mance-based studies have examined the relationship among speed, strength, and power (15) and have addressed the theory that strength gains are specific to the speed at which training is provided (16). A number of exercise studies have shown varying degrees of speed-specific improvement in power and strength when training is performed at different contractile speeds in healthy young adults and athletes. Most of these studies found that the greatest strength and power improvements occurred at or near the velocity at which training was provided (17-19). To date, however, there have been no reports of speed-specific training in older persons.

Studies examining speed-specific changes in muscle performance have focused on knee extension (19). There is only limited information on speed-specific training adaptations (20,21) in the dorsiflexors (22) and knee flexors (21), and no studies have examined speed specificity in the plantar flexors. Our study was based on the hypothesis that dif-

ferential speed-specific changes would occur during upper and lower leg training due to differences in muscle fiber type distribution (22,23), functional anatomy (24), maximum movement speed (25), and inherent contractile properties (26). It should also be noted that each of these factors changes with aging (23,27–29) and training (26,30–33). We compared the effects of high-speed versus low-speed isokinetic training on speed-specific changes in isokinetic power of the knee (extension, flexion) and ankle (dorsiflexion, plantar flexion) in healthy older women.

## METHODS

### Subjects

Twenty-eight healthy, independent-living women, ages 61 to 75, were recruited from the Miami-Dade metropolitan area. Four subjects left the study for personal reasons unrelated to the study. No subject had performed any resistance-training activities in the past 3 years. All subjects were fully informed of the procedures and signed an informed consent before beginning the study. All procedures were approved by the University of Miami Subcommittee for the Use and Protection of Human Subjects.

### Experimental Design

Before beginning the training program, subjects were tested isokinetically at  $3.14 \text{ rad}\cdot\text{s}^{-1}$  using a Biodex dynamometer (Biodex Corporation, Shirley, NY). The test for each joint was preceded by a five-repetition warm-up set using progressively more intense repetitions ranging from a perceived exertion of 50% to a maximum effort. The purpose of this warm-up set was to familiarize the subject with the feeling of isokinetic testing and to provide a movement-specific warm-up for the muscles to be tested. Following the warm-up, a 1-minute recovery was provided. The test set consisted of three maximal efforts. The peak torque value for knee extension of the right leg was used to match the subjects. After this process was completed, matched subjects were randomly assigned to one of three groups: a high-speed (HS) training group, a low-speed (LS) training group, or a control (C) group, using a random numbers table. Of the four subjects who left the study, one was from the HS group, one was from the C group, and two were from the LS group. The characteristics of each group are presented in Table 1. After assignment to groups and before training, the performance of subjects' knees and ankles was tested to establish their average power (AP) values at  $1.05 \text{ rad}\cdot\text{s}^{-1}$ ,  $3.14 \text{ rad}\cdot\text{s}^{-1}$ , and  $5.24 \text{ rad}\cdot\text{s}^{-1}$ . After completion of the 12-week training program, subjects were again tested to establish the impact of the individual protocols on these variables. The

same technician performed all tests and was blinded concerning the LS, HS, or C group assignment.

### Isokinetic Testing

A Biodex isokinetic dynamometer (Biodex Corporation, Shirley, NY) was used for testing the AP of the right leg. Settings were adjusted to provide optimal mechanical advantage for each subject, and these settings were recorded and used for both baseline and post-training measures. Each subject was familiarized with the testing protocol and underwent three practice trials before the actual testing. Subjects were given two warm-up repetitions (50% and 75% perceived effort) and a short recovery before the testing set. The technician gave verbal encouragement throughout the testing session. The muscle actions (knee extension and flexion, ankle dorsiflexion, and plantar flexion) and testing speeds ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ,  $3.14 \text{ rad}\cdot\text{s}^{-1}$ , and  $5.24 \text{ rad}\cdot\text{s}^{-1}$ ) were randomly assigned to each subject, and the testing sequence for that subject was held constant for the baseline and post-training sessions.

### Training

Both the HS and LS training groups trained three times a week for 12 weeks. All training was performed on the Biodex dynamometer under isokinetic conditions. The training speeds for each functional movement and the number of repetitions per training set for each group are shown in Table 2. A minimum of 2 minutes rest was provided between sets and 5 minutes between exercises. Knee extension and flexion were performed as reciprocal movements in one set and ankle plantar flexion and dorsiflexion as reciprocal movements during the other. The number of repetitions necessary to equilibrate total work at each speed was computed using data collected earlier on 104 older individuals, 62 to 78 years of age (J.F. Signorile, unpublished data, 1995). The C group performed a series of 10 active assisted stretches using a FlexMate stretching rope (Promise Enterprises, Jackson, MS). The stretches were designed to target all major muscle groups including the knee extensors, knee flexors, dorsiflexors, plantar flexors, shoulder adductors, shoulder abductors, shoulder flexors, shoulder extensors, elbow flexors, and elbow extensors.

### Statistical Analysis

All data were explored with descriptive statistics. Separate repeated measures analysis of variance (ANOVA) for knee extension, knee flexion, dorsiflexion, and plantar flexion was performed for the AP measured at each testing speed ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ,  $3.14 \text{ rad}\cdot\text{s}^{-1}$ , and  $5.24 \text{ rad}\cdot\text{s}^{-1}$ ), with group (i.e., C, HS, or LS) as the between-factor and time

Table 1. Characteristics of Subjects

Training Group	<i>n</i>	Age (y)	Weight (kg)	Height (cm)
HS	9	68.37 ± 1.42	65.19 ± 4.33	160.61 ± 1.10
LS	8	68.76 ± 1.62	68.38 ± 3.86	163.13 ± 1.47
C	7	69.01 ± 1.75	68.17 ± 3.65	154.93 ± 1.30

Notes: Values are means ± SE. HS = high-speed training group; LS = low-speed training group; C = control group.

Table 2. Training Protocols

Joint	Movement	Group	Speed ( $\text{rad}\cdot\text{s}^{-1}$ )	Repetitions
Knee	Extension/flexion	HS	4.73	10
		LS	1.05	6
Ankle	Plantar flexion/dorsiflexion	HS	3.14	8
		LS	1.05	6

Note: HS = high speed; LS = low speed.

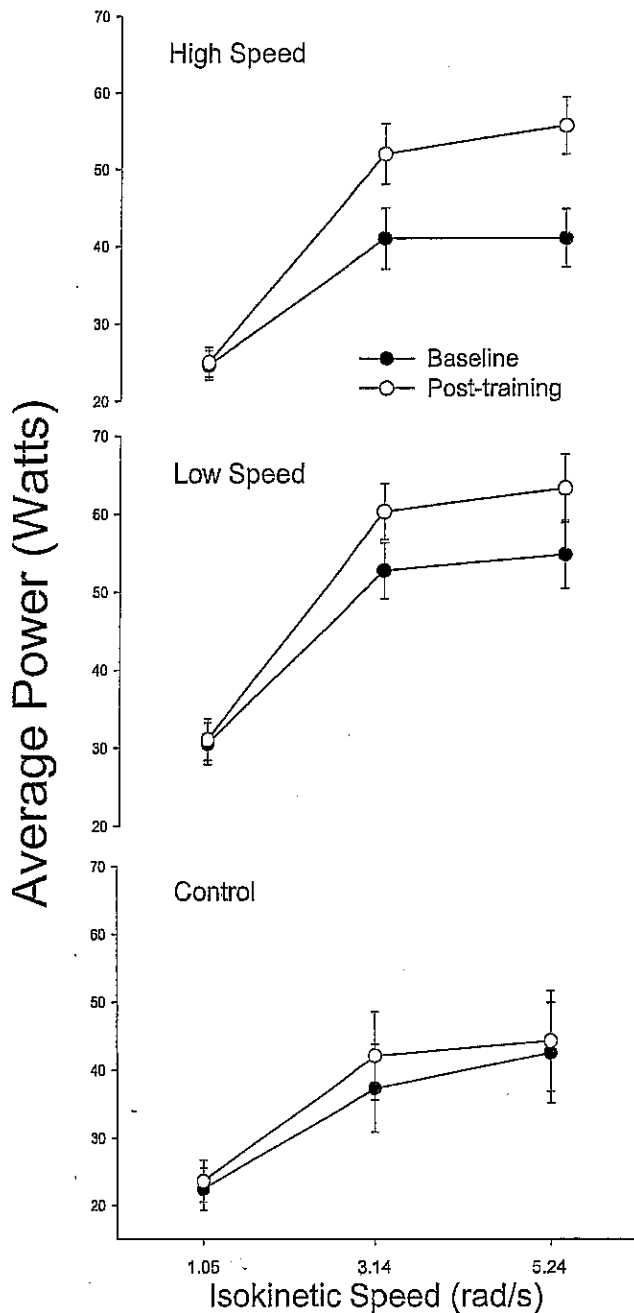


Figure 2. Average power curves for the knee flexors. Symbols represent mean  $\pm$  SE. Filled circles represent baseline values, while open circles represent post-training values.

LS training favoring the lower leg and HS training favoring the upper leg. The lack of significant strength improvements by the C group was expected because little or no external loading occurred during the active-assisted stretching protocol. Knowledge of optimal training speeds for the upper and lower leg should improve preventive exercise prescription for older persons.

#### Knee Extension

Our results, showing AP improvements ( $\Delta$ AP) at the higher testing speeds by the HS group, are similar to those

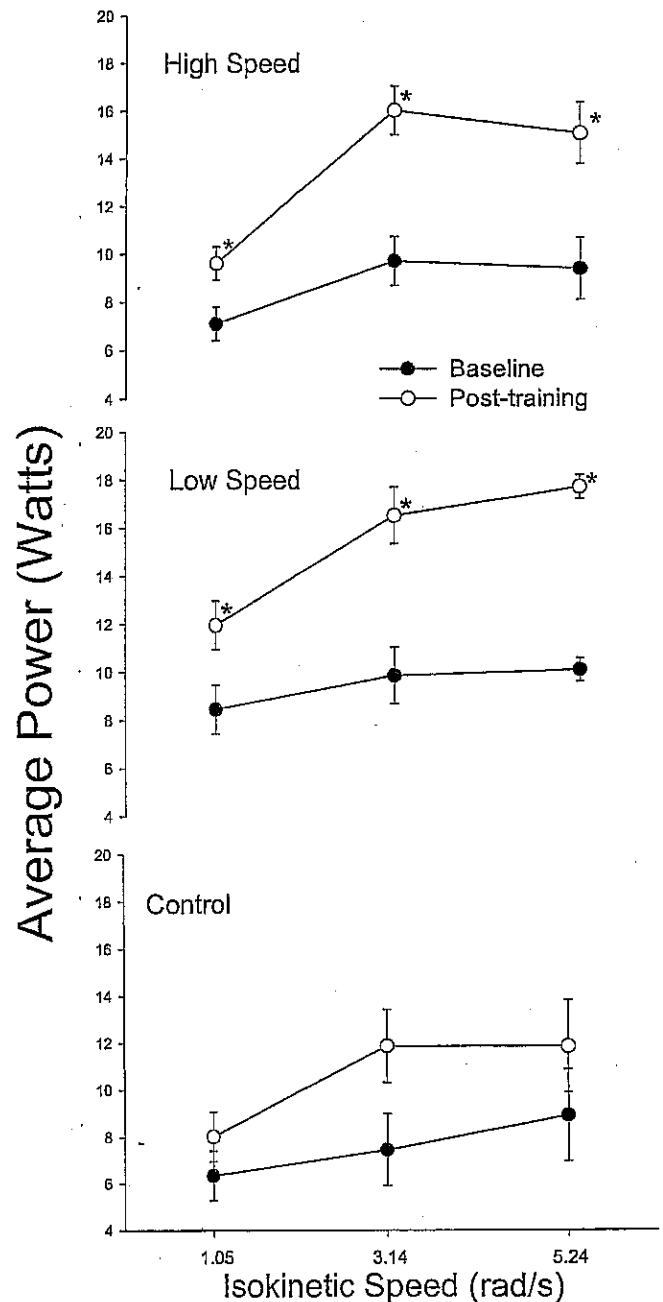


Figure 3. Average power curves for the ankle dorsiflexors. \*Significant improvement between baseline and post-training values. Symbols represent mean  $\pm$  SE. Filled circles represent baseline values, while open circles represent post-training values.

reported by Kanehisa and Miyashita (18), the only other study to evaluate speed-specific changes in isokinetic power as a result of isokinetic training. However, in contrast to their results, which indicated that the low-speed training group ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ) produced significant improvements at all speeds tested ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ,  $3.14 \text{ rad}\cdot\text{s}^{-1}$ , and  $5.24 \text{ rad}\cdot\text{s}^{-1}$ ), our LS group showed no improvements at any testing speed. One explanation for this difference may be that Kanehisa and Miyashita (18) examined young male subjects while we studied older women. Because strength (34), rate of torque

(i.e., baseline vs post-training) as the within-factor. All main effects and interaction effects were examined. If the group  $\times$  time interaction was significant, post hoc Bonferroni tests of group differences across changes between baseline and post-training were performed. Because of the homogeneity of age, gender, and race/ethnicity among the C, HS, and LS groups, these covariates were not included in the repeated measures ANOVA. An accepted probability level of  $p \leq .05$  was used for all statistical tests.

All analyses were performed using the SAS System for Windows (release 8.02). The "PROC MIXED" procedure was used for the repeated measures analysis of variance (SAS Institute, Cary, NC).

## RESULTS

The compliance rate for the HS training group was 95.4%. The LS group attended 93.2% of their sessions. The C group compliance rate was 95.8%.

### Knee Extension

Figure 1 shows the baseline and post-training power-isokinetic speed curves for each training condition (HS, LS, and C, respectively). The repeated measures ANOVA revealed significant changes across time at each testing speed. However, the Bonferroni test indicated that no significant improvements were made by any treatment group at 1.05  $\text{rad}\cdot\text{s}^{-1}$ . At 3.14  $\text{rad}\cdot\text{s}^{-1}$  and 5.24  $\text{rad}\cdot\text{s}^{-1}$ , a significant treatment  $\times$  time interaction was detected. The Bonferroni test revealed that only the HS group made a significant improvement in AP (mean  $\pm$  SE) (3.14  $\text{rad}\cdot\text{s}^{-1}$ ,  $\Delta\text{AP} = 25.96 \pm 5.06$  W,  $p = .0007$ ; 5.24  $\text{rad}\cdot\text{s}^{-1}$ ,  $\Delta\text{AP} = 32.49 \pm 6.34$  W,  $p = .0004$ ).

### Knee Flexion

Baseline and post-training isokinetic AP curves during knee flexion are shown in Figure 2. Repeated measures ANOVA on knee flexion data at 1.05  $\text{rad}\cdot\text{s}^{-1}$ , 3.14  $\text{rad}\cdot\text{s}^{-1}$ , and 5.24  $\text{rad}\cdot\text{s}^{-1}$  revealed no significant time  $\times$  treatment interactions. In addition, no significant improvements were made by any treatment group across time.

### Ankle Dorsiflexion

Figure 3 shows the baseline and post-training AP curves for ankle dorsiflexion. The repeated measures ANOVA revealed no significant treatment  $\times$  time interactions; however, a significant time effect was detected at all testing speeds ( $p = .0001$ ). The Bonferroni test showed significant improvements by both the LS and HS groups at 1.05  $\text{rad}\cdot\text{s}^{-1}$  (HS  $\Delta\text{AP} = 2.51 \pm 0.55$  W,  $p = .0036$ ; LS  $\Delta\text{AP} = 3.50 \pm 0.36$  W,  $p = .0003$ ), 3.14  $\text{rad}\cdot\text{s}^{-1}$  (HS  $\Delta\text{AP} = 6.31 \pm 1.06$  W,  $p = .0001$ ; LS  $\Delta\text{AP} = 6.66 \pm 1.01$  W,  $p = .0001$ ), and 5.24  $\text{rad}\cdot\text{s}^{-1}$  (HS  $\Delta\text{AP} = 5.65 \pm 0.82$  W,  $p = .0001$ ; LS  $\Delta\text{AP} = 7.60 \pm 0.65$  W,  $p = .0001$ ). No significant changes were seen in the C group at any testing speed.

### Ankle Plantar Flexion

Baseline and post-training isokinetic AP during plantar flexion for the HS, LS, and C groups, respectively, are presented in Figure 4. The repeated measures ANOVA re-

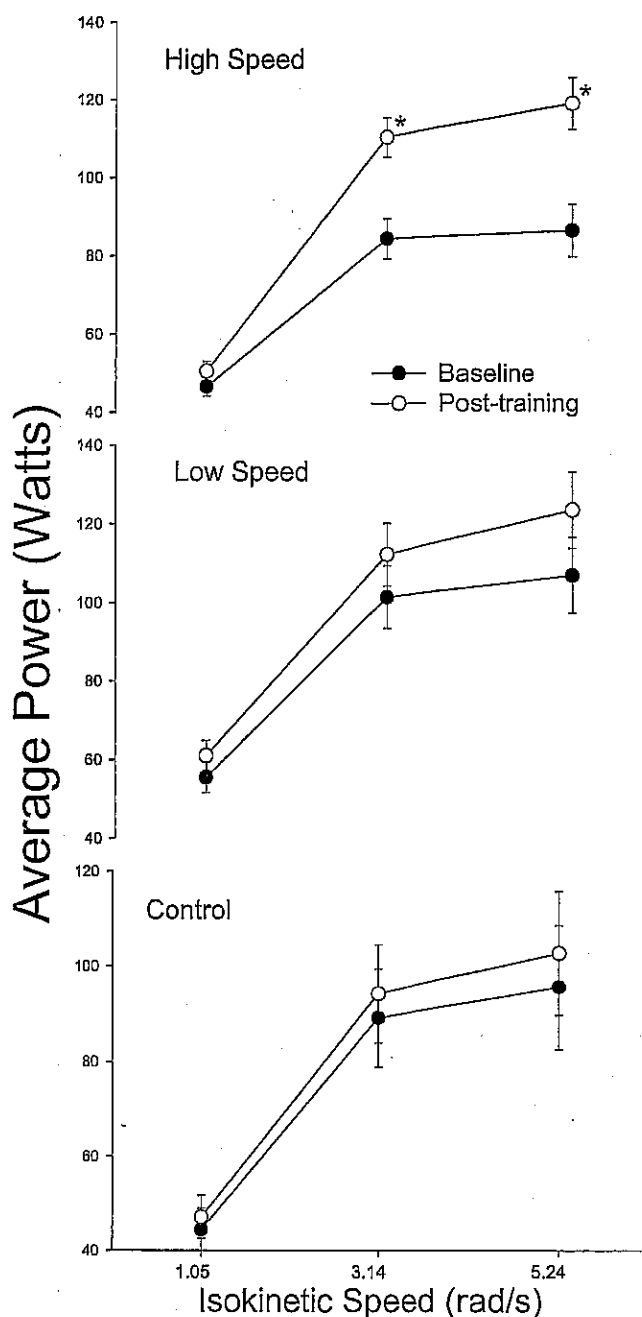


Figure 1. Average power curves for the knee extensors. \*Significant improvement between baseline and post-training values. Symbols represent mean  $\pm$  SE. Filled circles represent baseline values, while open circles represent post-training values.

vealed significant time effects at both 1.05  $\text{rad}\cdot\text{s}^{-1}$  and 3.14  $\text{rad}\cdot\text{s}^{-1}$ . The Bonferroni test showed that the power improvements were exclusive to the LS group ( $\Delta\text{AP}$  at 1.05  $\text{rad}\cdot\text{s}^{-1} = 9.12 \pm 2.63$  W,  $p = .0132$ ;  $\Delta\text{AP}$  at 3.14  $\text{rad}\cdot\text{s}^{-1} = 12.47 \pm 3.53$  W,  $p = .0310$ ).

## DISCUSSION

The major finding of this study was that LS and HS training differentially improved upper and lower leg AP, with

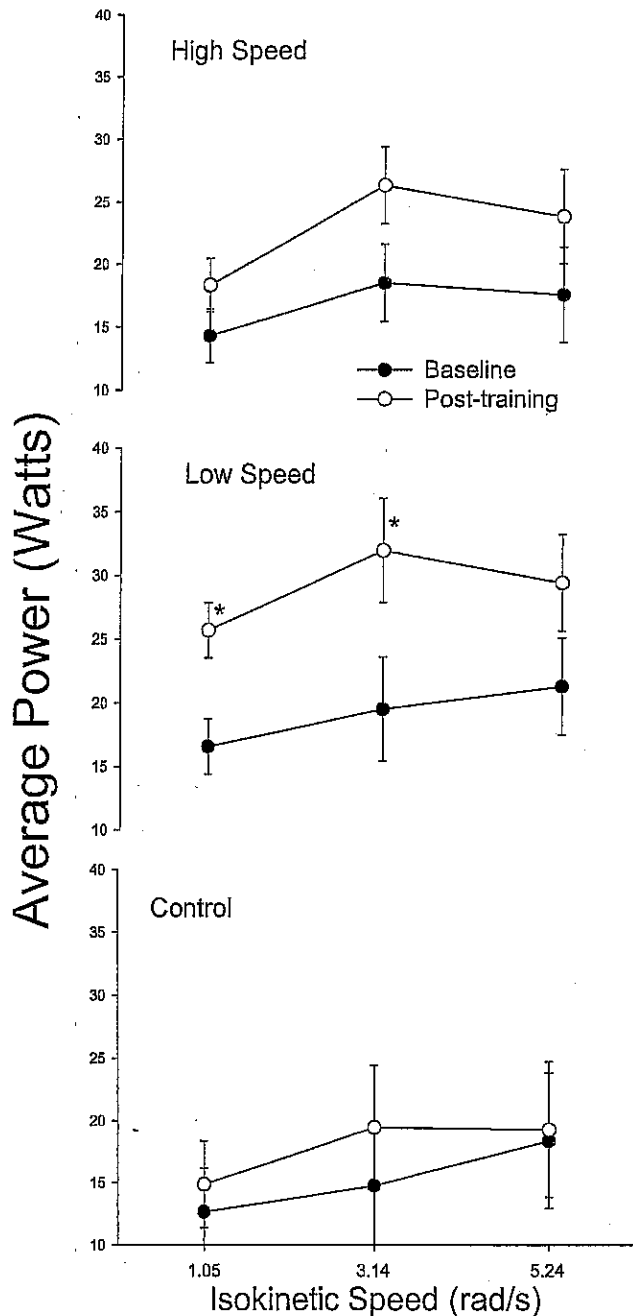


Figure 4. Average power curves for the ankle plantar flexors. \*Significant improvement between baseline and post-training values. Symbols represent mean  $\pm$  SE. Filled circles represent baseline values, while open circles represent post-training values.

production (35), and muscle cross-sectional area (especially of the type II fibers) (27) are affected by age and gender, baseline values in our group would be expected to be lower than those produced in the group studied by Kanehisa and Miyashita (18). Our results suggest a greater need to incorporate faster training speeds into resistance training programs designed to target upper leg function in older individuals. Our knee extension AP findings are similar to the knee torque changes reported by Coyle and colleagues (19), who stated that their HS training group ( $5.24 \text{ rad}\cdot\text{s}^{-1}$ ) showed

significantly greater improvements than a placebo group at intermediate ( $3.14 \text{ rad}\cdot\text{s}^{-1}$ ) and high ( $5.24 \text{ rad}\cdot\text{s}^{-1}$ ), but not at low ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ), testing speeds, while their LS group improved only at  $1.05 \text{ rad}\cdot\text{s}^{-1}$ . In contrast, our LS group showed no power improvements at any test speed. The lack of improvement by our LS group may have been the result of the lower training speed employed during our study, the age of the participants, or the fact that Coyle and colleagues (19) examined torque rather than power, which has a speed component built into its computation.

Another study measuring torque changes over 4 weeks of isokinetic training of the knee extensors at either  $1.68 \text{ rad}\cdot\text{s}^{-1}$  or  $4.19 \text{ rad}\cdot\text{s}^{-1}$  in young men produced results similar to those seen in our HS group, with improvements at  $2.51 \text{ rad}\cdot\text{s}^{-1}$ ,  $3.35 \text{ rad}\cdot\text{s}^{-1}$ , and  $4.19 \text{ rad}\cdot\text{s}^{-1}$  (20). However, unlike the LS group in our study, subjects in the study by Caiozzo and colleagues (20), who trained at  $1.68 \text{ rad}\cdot\text{s}^{-1}$ , produced significant improvements at velocities of 0, 0.84, 1.68, 2.51, 3.35, and  $4.19 \text{ rad}\cdot\text{s}^{-1}$ . Once again, differences in age, gender, and the dependent variable (torque vs power) may all have been confounding factors in the comparison.

Moffroid and Whipple (17) also examined the effects of HS and LS training on knee extensor torque production. Their HS group exercised at  $1.89 \text{ rad}\cdot\text{s}^{-1}$ , and their LS group trained at  $0.63 \text{ rad}\cdot\text{s}^{-1}$ . The LS subjects made significantly greater increases in torque production at low testing speeds ( $0.63 \text{ rad}\cdot\text{s}^{-1}$ ,  $0.31 \text{ rad}\cdot\text{s}^{-1}$ ) than at the higher testing speeds ( $0.95$ ,  $1.26$ ,  $1.58$ ,  $1.89 \text{ rad}\cdot\text{s}^{-1}$ ), while the HS group produced significant increases at all test speeds. The results of their HS training group are similar to our power results, showing improvements across the entire speed spectrum. However, they differ dramatically from those seen in our LS group, where we recorded no significant improvements in power. Once again, differences in gender, age, and the outcome variable (torque vs power) are likely reasons. In addition, the lower training and testing speeds employed by Moffroid and Whipple (17) may have produced a different training stimulus from those used in our study.

#### Knee Flexion

Of the studies examining the speed-specific impact of isokinetic resistance training on leg power and torque, only the study by Housh and Housh (21) reported knee flexion data. While we found no significant increases in AP by any of the groups tested (HS, LS, or C), they reported significant increases in peak torque at all testing speeds ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ,  $2.10 \text{ rad}\cdot\text{s}^{-1}$ ,  $3.14 \text{ rad}\cdot\text{s}^{-1}$ ,  $4.20 \text{ rad}\cdot\text{s}^{-1}$ , and  $5.24 \text{ rad}\cdot\text{s}^{-1}$ ) as a result of training at  $2.10 \text{ rad}\cdot\text{s}^{-1}$ . It should be noted that the post hoc analysis did show a trend toward speed-specific increases in power for the HS group at both  $3.14 \text{ rad}\cdot\text{s}^{-1}$  ( $\Delta\text{AP} = 10.97 \text{ W}$ ;  $p = .1138$ ) and  $5.24 \text{ rad}\cdot\text{s}^{-1}$  ( $\Delta\text{AP} = 14.62 \text{ W}$ ;  $p = .1677$ ) even after the Bonferroni adjustment. Methodological differences between these two studies such as gender, age, and training speeds may, once again, explain the divergent results between the two studies. Additionally, because knee extension and flexion were trained as reciprocating movements during the same training set, the subjects may have placed greater concentration on the more dominant knee extensors than the knee flexors.

### *Ankle Dorsiflexion*

Only one other study has examined speed-specific training of the ankle dorsiflexors. In that study, Behm and Sale (22) trained eight men and eight women, aged  $20.9 \pm 0.5$  years, 3 days a week for 16 weeks. Their subjects trained using either high-speed isokinetic training at  $5.23 \text{ rad}\cdot\text{s}^{-1}$  or isometric training. Under both conditions, the subjects attempted to contract the muscle as strongly and rapidly as possible. Regardless of the training modality, subjects showed significant increases in peak torque at 1.04, 1.55, 3.02, 4.19, and  $5.23 \text{ rad}\cdot\text{s}^{-1}$ , with the greatest improvements at  $5.23 \text{ rad}\cdot\text{s}^{-1}$ . These torque results are similar to the training results seen for dorsiflexion power in our study, where both the HS and LS groups showed significant increases at all testing speeds.

### *Ankle Plantar Flexion*

To the best of our knowledge, no other studies have examined the impact of varied training speeds on power-velocity or force-velocity relationships during plantar flexion. Our data showing significant improvement by the LS group at  $1.05 \text{ rad}\cdot\text{s}^{-1}$  support the concept of speed specificity. The transfer of strength improvement to the higher testing speed of  $3.14 \text{ rad}\cdot\text{s}^{-1}$  reflects the results reported by Housh and Housh (21) for a number of other muscle groups. The difference between these results and those for other leg actions may have been dictated by a number of factors. Alway and colleagues (36) have noted that the triceps surae group has a lower rate of tension development than that of other muscles with similar fiber type distributions due to the compliance of the Achilles tendon. In addition, the gastrocnemius is a biarticular muscle, and its slackened condition when the knee is bent reduces its effectiveness as a plantar flexor (25,37). Because our training and testing utilized a knee angle of  $135^\circ$ , the contribution of the gastrocnemius muscle was reduced, and greater reliance was placed on the slower-contracting soleus muscle. Therefore, the HS group may not have been able to produce the necessary movement speed to develop sufficient torque to elicit a training effect.

### *Comparisons Among Muscle Groups*

Although the knee extension and knee flexion results for the HS and LS groups do mirror each other, the differences between the groups were significant only during knee extension. A number of researchers have reported that the knee flexors are more receptive to intermediate speed training than the knee extensors (38–40). One explanation is that the hamstrings have a higher proportion of type II fibers than the quadriceps group and can produce higher tension (41). Therefore, the HS stimulus that provided sufficient overload for the quadriceps group may not have been adequate for the hamstrings. The reduced training effect could have lessened the differences between the HS and LS groups.

The pattern of change in the ankle dorsiflexors differs from that at the knee or during ankle plantar flexion. The dorsiflexor improvements at all testing speeds may indicate that the small muscle mass and consequential greater tension per cross-sectional area of the dorsiflexors resulted in a greater training stimulus. Also, the ankle dorsiflexors have a far lower load-bearing requirement than the plantar flexors in normal everyday activities. In concert, these factors

would put the dorsiflexors at a lower initial level of performance and consequently at a steeper portion of the training curve than the plantar flexors.

The positive impact made by our HS training protocol on dorsiflexor performance at lower test speeds has been reported in studies examining other muscle groups (19,42). The significant improvements in dorsiflexion by the LS group at all speeds of testing are also not without precedent. Behm and Sale (22) noted that isometric training, employing high rates of tension development, produced strength gains similar to isokinetic training at high speeds across high, intermediate, and low testing speeds. A comparison of the shapes of the HS and LS dorsiflexion test curves with analogous curves from the knee extensors and flexors seems to demonstrate that the dorsiflexors cannot produce the high movement speeds seen during knee extension and flexion. The inability of the dorsiflexors to produce movement speeds comparable to the knee extensors and flexors may be attributable to their inherent contractile speed, smaller mass, or shorter functional lever system. In addition, the inability to produce substantially higher power values at higher isokinetic speeds and the continual rise in the test curve at  $5.24 \text{ rad}\cdot\text{s}^{-1}$  for the LS versus HS condition seem to argue for the use of lower training speeds for this muscle group.

The unique results seen during plantar flexion, where the only significant improvement was made by the LS group at  $1.05 \text{ rad}\cdot\text{s}^{-1}$ , may also be attributable to the training and testing speeds selected for use during this study. Detailed analysis of the test curves, using only the areas where the set isokinetic speed was attained, revealed that the HS group was able to meet the set speed only for short time periods, and the low torque values they produced indicate that they were training toward the top end of their speed spectrum (data not shown). Thus, the resistance component of their training was reduced, and the training effect was lessened. In contrast, the LS group, due to the lower speed setting of the dynamometer, received greater resistance and a more effective training stimulus throughout the range of motion. This explanation is strengthened by the comparative shapes of the test curves for both groups, which, unlike the sharply up-sloping curves seen for knee extension and flexion, showed a notable plateau or decline in power at  $5.24 \text{ rad}\cdot\text{s}^{-1}$ . These pattern differences suggest that our older women could not produce the movement speed necessary to perform the plantar flexion optimally during training and testing. Moreover, as was the case with the dorsiflexors, our results suggest that the HS training speed ( $3.14 \text{ rad}\cdot\text{s}^{-1}$ ) was too high. Further studies are necessary to ascertain the optimal training speed for this muscle group.

In summary, our results for the knee extensors confirm the importance of HS training in shifting the power-velocity relationship and also indicate that a transfer of the training effect to somewhat lower (intermediate) speeds of movement can be expected for the knee extensors. With respect to power improvements in the lower leg (ankle dorsiflexors and plantar flexors), our data suggest that low to intermediate training speeds are better than high speeds.

### *Significance for Independence and Fall Prevention*

Skelton and colleagues (43,44) have reported that leg extensor power declines approximately 3.5% per year between

the ages of 60 and 89, and that power is directly related to ADL functions such as stair climbing and lifting a shopping bag. Bassey and colleagues (6) reported significant correlations between leg extensor power and daily activities such as stair climbing, rising from a chair, and walking without a walker. In community-dwelling older women, Foldvari and colleagues (5) reported that, among all physiological factors tested, leg power showed the highest correlation ( $r = -.47$ ;  $p < .0001$ ) with self-reported functional status. In addition, the association between gait speed and independence is well established (7,9–11). Dutta and colleagues (45) noted that many of the activities of everyday living, such as stopping abruptly to avoid a car at a crosswalk, recovering from a stumble, or grabbing a handrail, depend on speed, and, therefore, speed must be adequately addressed for an exercise program to have positive effects on ADL performance.

When fall prevention is considered, power and contractile speed again present as important modifying factors. Failure to recognize this fact may set too low a standard for prescribing preventive exercises. In an examination of 34 nursing home residents classified as fallers and nonfallers, Whipple and colleagues (3) found that the strength and power of the knee extensors and flexors, as well as the ankle dorsiflexors and plantar flexors, were lower in fallers than in nonfallers. A biomechanical analysis by Grabiner and colleagues (4) found that lower extremity muscular power and the ability to restore control of the flexing trunk were the two major determining factors. Greenspan and colleagues (46) reported that most hip fractures occur during falls to the back and side, while Cummings and Nevitt (12) and Smeesters and colleagues (13) independently showed that gait speed influences the direction of falls, with higher gait speeds dictating forward falls.

A number of studies have shown that both strength and power can be improved in older individuals using standard resistance training protocols (33,44,47–51). However, when strength, power, and movement speed are considered in relation to fall prevention and the preservation of independence, there is little doubt that increasing power across the velocity spectrum would have significant benefits in an older population. Our finding, that the upper and lower leg may respond differently to HS and LS training, opens the way for joint-specific exercise prescriptions targeting speed and power in older persons. These prescriptions should provide more effective training to improve ADL performance and prevent falls in older individuals.

#### ACKNOWLEDGMENTS

We are grateful for support from the Teaching Nursing Home program, funded by the State of Florida Agency for Health Care Administration, during the data analysis and manuscript preparation portions of this project. In addition, we thank the University of Miami students who helped with data collection and training, including Ms. Laura Myerburg, Ms. Rachael Epstein, and Mr. Brandon Feldman.

Address correspondence to Dr. Joseph F. Signorile, Stein Gerontological Institute, 5200 NE Second Ave., Miami, FL 33137. E-mail: jsignorile@miami.edu

#### REFERENCES

1. Knuttgen HG, Kraemer WJ. Terminology and measurement in exercise performance. *J Appl Sports Sci Res.* 1987;1:1–10.
2. Newton RU, Kraemer WJ. Developing explosive muscular power: implications for mixed methods training strategy. *Natl Strength Conditioning Assoc J.* 1994;16:20–31.
3. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. *J Am Geriatr Soc.* 1987;35:13–20.
4. Grabiner MD, Koh TJ, Lundin TM, Jahnigen DW. Kinematics of recovery from a stumble. *J Gerontol Med Sci.* 1993;48:M97–M102.
5. Foldvari M, Clark M, Laviolette LC, et al. Association of muscle power with functional status in community-dwelling elderly women. *J Gerontol Med Sci.* 2000;55A:M192–M199.
6. Bassey EJ, Fiatarone MA, O'Neill EF, Kelly M, Evans WJ, Lipsitz LA. Leg extensor power and functional performance in very old men and women. *Clin Sci (Colch).* 1992;82(3):321–327.
7. Gibbs J, Hughes S, Dunlop D, Singer R, Chang RW. Predictors of change in walking velocity in older adults. *J Am Geriatr Soc.* 1996;44:126–132.
8. Buchner D, Larson EB, Wagner EH, Koepsell TD, de Lateur BJ. Evidence for a non-linear relationship between leg strength and gait speed. *Age Ageing.* 1996;25(5):386–391.
9. Friedman PJ, Richmond DE, Baskett JJ. A prospective trial of serial gait speed as a measure of rehabilitation in the elderly. *Age Ageing.* 1988;17(4):227–235.
10. Judge JO, Schechtman K, Cress E. The relationship between physical performance measures and independence in instrumental activities of daily living. The FICSIT Group. Frailty and Injury: Cooperative Studies of Intervention Trials. *J Am Geriatr Soc.* 1996;44:1332–1341.
11. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol Med Sci.* 1994;49:M85–M94.
12. Cummings SR, Nevitt MC. A hypothesis: the causes of hip fractures. *J Gerontol Med Sci.* 1989;44:M107–M111.
13. Smeesters C, Hayes WC, McMahon TA. Disturbance type and gait speed affect fall direction and impact location. *J Biomech.* 2001;34(3):309–317.
14. Kraemer WJ, Fleck SJ, Evans WJ. Strength and power training: physiological mechanisms of adaptation. *Exerc Sport Sci Rev.* 1996;24:363–397.
15. Häkkinen K, Komi PV. Effect of explosive type strength training on electromyographic and force production characteristics of leg extensor muscles during concentric and various stretch-shortening cycle exercises. *Scand J Sports Sci.* 1985;7(2):65–76.
16. Bell GJ, Wenger HA. Physiological adaptations to velocity-controlled resistance training. *Sports Med.* 1992;13(4):234–244.
17. Moffroid M, Whipple RH. Specificity of speed of exercise. *Phys Ther.* 1970;50(12):1692–1700.
18. Kanehisa H, Miyashita M. Specificity of velocity in strength training. *Eur J Appl Physiol Occup Physiol.* 1983;52(1):104–106.
19. Coyle EF, Feiring DC, Rotkis TC, et al. Specificity of power improvements through slow and fast isokinetic training. *J Appl Physiol.* 1981;51:1437–1442.
20. Caiozzo VI, Perrine JJ, Edgerton VR. Training-induced alterations of the in vivo force-velocity relationship of human muscles. *J Appl Physiol.* 1981;51:750–754.
21. Housh DJ, Housh TJ. The effects of unilateral velocity-specific concentric strength training. *J Orthop Sports Phys Ther.* 1993;17(5):252–256.
22. Behm DG, Sale DG. Intended rather than actual movement velocity determines velocity-specific training response. *J Appl Physiol.* 1993;74:359–368.
23. Häkkinen K, Newton RU, Gordon SE, et al. Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *J Gerontol Biol Sci.* 1998;53A:B415–B423.
24. Thompson CW, Floyd RT. *Manual of Structural Kinesiology.* 12th ed. St. Louis, MO: Mosby; 1994.
25. Tamaki H, Kitada K, Akamine T, Sakou T, Kurata H. Electromyogram patterns during plantarflexions at various angular velocities and knee angles in human triceps surae muscles. *Eur J Appl Physiol Occup Physiol.* 1997;75:1–6.
26. Alway SE, MacDougall JD, Sale DG, Sutton JR, McComas AJ. Functional and structural adaptations in skeletal muscle of trained athletes. *J Appl Physiol.* 1988;64:1114–1120.

27. Lexell J. Human aging, muscle mass, and fiber type composition. *J Gerontol Biol Sci Med Sci*. 1995;50A(Special Issue):11-16.
28. Larsson L, Li X, Frontera WR. Effects of aging on shortening velocity and myosin isoform composition in single human skeletal muscle cells. *Am J Physiol*. 1997;272:C638-C649.
29. Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R. Aging of skeletal muscle: a 12-yr longitudinal study. *J Appl Physiol*. 2000;88:1321-1326.
30. Häkkinen K. Neuromuscular and hormonal adaptations during strength and power training. *J Sports Med Phys Fitness*. 1989;29:9-26.
31. Staron RS, Malicky ES, Leonardi MJ, Falkel JE, Hagerman FC, Dudley GA. Muscle hypertrophy and fast fiber type conversions in heavy resistance-trained women. *Eur J Appl Physiol Occup Physiol*. 1990;60:71-79.
32. Hunter SK, Thompson MW, Rueli PA, et al. Human skeletal sarcoplasmic reticulum Ca<sup>2+</sup> uptake and muscle function with aging and strength training. *J Appl Physiol*. 1999;86:1858-1865.
33. Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG, Evans WJ. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol*. 1988;64:1038-1044.
34. Frontera WR, Hughes VA, Lutz KJ, Evans WJ. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol*. 1991;71:644-650.
35. Behm DG, Sale DG. Voluntary and evoked muscle contractile characteristics in active men and women. *Can J Appl Physiol*. 1994;19:253-265.
36. Alway SE, MacDougall JD, Sale DG. Contractile adaptations in the human triceps surae after isometric exercise. *J Appl Physiol*. 1989;66:2725-2732.
37. Signorile JF, Applegate B, Duque M, Cole N, Zink A. Selective recruitment of the triceps surae muscles with changes in knee angle. *J Strength Cond Res*. In press.
38. Bell GJ, Petersen SR, Quinney HA, Wenger HA. Sequencing of endurance and high-velocity strength training. *Can J Sports Sci*. 1988;13:214-219.
39. Lesmes GR, Costill DL, Coyle EF, Fink WJ. Muscle strength and power changes during maximal isokinetic training. *Med Sci Sports*. 1978;10(4):266-269.
40. Petersen S, Miller G, Quinney HA, Wenger HA. The influence of high-velocity resistance training on aerobic power. *J Orthop Sports Phys Ther*. 1988;9:339-344.
41. Garrett WE Jr, Califf JC, Basset FH 3rd. Histochemical correlates of hamstring injuries. *Am J Sports Med*. 1984;12(2):98-103.
42. Dudley GA, Djamil R. Incompatibility of endurance- and strength-training modes of exercise. *J Appl Physiol*. 1985;59:1446-1451.
43. Young A, Skelton A. Applied physiology of strength and power in old age. *Int J Sports Med*. 1994;15(3):149-151.
44. Skelton DA, Young A, Greig CA, Malbut KE. Effects of resistance training on strength, power, and selected functional abilities of women aged 75 and older. *J Am Geriatr Soc*. 1995;43:1081-1087.
45. Dutta C, Hadley EC, Lexell J. Sarcopenia and physical performance in old age: overview. *Muscle Nerve*. 1997;5(Suppl):S5-S9.
46. Greenspan SL, Myers EJ, Maitland LA, Resnick NM, Hayes WC. Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. *JAMA*. 1994;271(2):128-133.
47. Fiatarone MA, Evans WJ. Exercise in the oldest old. *Top Geriatr Rehabil*. 1990;5(2):63-77.
48. Jozsi AC, Campbell WW, Joseph L, Davey SL, Evans WJ. Changes in power with resistance training in older and younger men and women. *J Gerontol Med Sci*. 1999;54A:M591-M596.
49. Tracy BL, Ivey FM, Huribut D, et al. Muscle quality. II. Effects of strength training in 65- to 75-yr-old men and women. *J Appl Physiol*. 1999;86:195-201.
50. Cohn SH, Vartsky D, Yasumura S, et al. Compartmental body composition based on total-body nitrogen, potassium, and calcium. *Am J Physiol*. 1980;239(6):E524-E530.
51. Novak LP. Aging, total body potassium, fat-free mass, and cell mass in males and females between ages 18 and 85 years. *J Gerontol*. 1972;27:438-443.

Received January 28, 2002

Accepted April 19, 2002