The Relationship between Lower Extremity Strength and Power to Everyday Walking Behaviors in Older Adults with Functional Limitations

Michael L. Puthoff, PT, PhD;[1] Kathleen F. Janz, EdD;[2] David H. Nielsen, PT, PhD[3]

[1] St. Ambrose University, Physical Therapy Department, Davenport, IA
[2] University of Iowa, Department of Health and Sport Studies, Iowa City, IA
[3] University of Iowa, Graduate Program in Physical Therapy and Rehabilitation Science, Iowa City, IA

ABSTRACT

Purpose: While lower extremity strength and power show a relationship to laboratory measures of walking in older adults, the relationship of strength and power to walking behaviors in a community setting is unclear. The purpose of this study was to examine the relationship between lower extremity strength, peak power, power at a low relative intensity, and power at a high relative intensity to everyday walking behaviors in older adults. **Methods:** Thirty community-dwelling older adults (mean age = 77.3 ± 7.0, 25 females, 5 males) took part in the study. Lower extremity strength and power were measured with a pneumatic resistance leg press. An accelerometer activity monitor was used to measure walking behaviors across 6 days with total steps, distance, and walking speed used as outcome measures. **Results**: Peak power (R^2 = 0.16) was significantly related to total steps. Strength (R^2 = 0.23), peak power (R^2 = 0.44), power at low relative intensity (R^2 = 0.41), and power at high relative intensity (R^2 = 0.34) were significantly related to distance. Strength (R^2 = 0.39), peak power (R^2 = 0.50), power at low relative intensity (R^2 = 0.38), and power at high relative intensity (R^2 = 0.48) were significantly related to walking speed. **Conclusions**: Lower extremity strength, peak power, power at a low relative intensity, and power at a high relative intensity are all related to walking behaviors in older adults with peak power having the strongest relationship.

Key Words: strength, power, aged, physical activity, accelerometer

INTRODUCTION

The importance of physical activity for older adults has been acknowledged through numerous research studies and is promoted as a key intervention in maintaining health by organizations such as the American College of Sports Medicine and Healthy People 2010.[1-3] One of the most common form of physical activity that older adults participate in is walking.[4] Walking, whether as part of a formal exercise program or performed through daily activities, has many benefits for older adults including improved mobility, increased quality of life, improved bone health, lower rates of hip fractures, improved functional capacity, and even lower mortality rates.[5-9] Additionally, walking is considered a low impact, safe, and inexpensive form of physical activity.[10] Unfortunately 61% of Americans 65 years of age or older do not achieve the recommended physical activity level of 30 or more minutes of moderate intensity activity on most days of the week, and 34% are completely sedentary.[11] Increasing physical activity levels, through such activities as walking, has the potential to improve the health and quality of life of older adults,[12] but in order to do this, health care professionals need a better understanding of the factors that limit activity.

One factor that may be responsible for the low levels of physical activity and walking in older adults is the decline in muscle mass with a specific atrophy of Type II muscle fibers that takes place during the aging process.[13-15] This loss of skeletal muscle, termed sarcopenia, is a pathological condition that can lead to the development of impairments in muscle strength and power.[16,17] Muscle strength is defined as the ability of a muscle or muscle group to exert a maximal force or torque at a specific velocity during a muscle contraction. Muscle power is characterized by the product of force production and the velocity at which the force is produced.[18] Muscle strength and power have both been shown to decline with the aging process with power declining at a faster rate than strength.[13,19,20] Researchers have found that those older adults with higher levels of lower extremity strength and power demonstrate greater walking speeds and distances than those with lower levels of strength and power.[21-23] In these studies, researchers have found that peak power in the lower extremities consistently demonstrates a greater relationship to walking speed and distance than strength. Additionally, some study findings suggest that power and speed of movement at a low relative intensity may have a stronger relationship on walking performance than power and speed at a high relative intensity because walking is a low intensity activity.[24,25]

In these studies, the measurement of walking has been completed in the laboratory setting (gait speed across a short distance or distance ambulated during walk tests) to establish the capacity for walking. This approach may not reflect the actual walking behaviors of older adults in the community. Environmental, social, and psychological factors have all been identified as determinants of community walking.[26-28] Because of the influence these factors, the association of lower extremity strength and power to actual walking behavior may not be a great as previous studies have indicated.

Given the importance of physical activity for older adults and the number of older adults who chose walking as their form of

Address all correspondence to: Michael L. Puthoff, PT, PhD, Assistant Professor, Physical Therapy Department, St. Ambrose University, 518 W. Locust St., Davenport, IA 52803 Ph: 563-333-6009, Fax: 563-333-6410 (puthoffmichaell@sau.edu).

physical activity, a better understanding of how strength and power are related to everyday walking behaviors may provide guidance in the design of training programs to increase actual walking levels. The purpose of this study was to examine the relationship between lower extremity strength, peak power, power at a low relative intensity [(40% one repetition maximum (1-RM)], and power at a high relative intensity (90% 1-RM) to walking behaviors (average steps per day, average distance walked per day, and average walking speed measured with an activity monitor) in community-dwelling older adults with functional limitations. It was hypothesized that power at a low relative intensity would have the greatest relationship on walking behaviors because walking is considered a low intensity activity.

METHODS

Study Design

This study employed a cross sectional design. Subjects took part in 3 sessions. Figure 1 displays the outcome measures used during each session and the time between sessions.

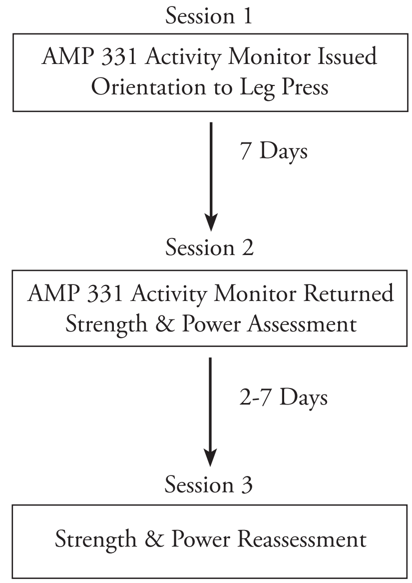

Figure 1. Study design.

Study Population

Thirty community-dwelling older adults (mean age = 77.3 ± 7.0, 25 females, 5 males) with self-reported mild to moderate functional limitations were recruited to participate in this study. Those with one or more limitations on the physical function subscale of the Medical Outcome Survey (SF-36)[29] were considered to have self-reported mild to moderate limitations. The decision to seek individuals with limitations was made so the subjects better reflected the general population of older adults who present with impairments that affect function. Exclusion criteria included acute or terminal illnesses, myocardial infarction in the last 6 months, moderate or severe chronic obstructive pulmonary disease, uncontrolled hypertension, uncontrolled metabolic disease, acute orthopedic injuries, recent unhealed fractures, neurological disease, muscular disease, inability to ambulate, or significant cognitive impairments (<23 on the Folstein Mini Mental State Examination[30]). Each subject provided written informed consent prior to any data collection. The 30 subjects on average had 2.7 ± 1.4 chronic health conditions, took 4.7 ± 3.4 prescription medications, and reported 4.4 ± 2.0 limitations on the SF-36 physical function subscale. The average body mass index of the subjects was 29.8 ± 8.1 kg/m^2.

Muscle Performance Testing

The Keiser 420 Leg Press (Keiser Corporation, Fresno, Calif) was used to assess bilateral lower extremity strength and power. The leg press is a piston pneumatic system that uses air pressure to create resistance. Inside each cylinder sensors measure changes in pressure and the positional movement of the piston inside the cylinder to calculate force and power production. This method of testing demonstrates high reliability and validity for the assessment lower extremity strength and power in older adults.[22,31,32]

The protocol used to test strength and power has been previously described in detail.[33] Briefly, subjects first completed an orientation session to the leg press during the first session. This allowed them to practice high velocity contractions and become familiar with the testing procedure. Assessment of strength and power took place during the second session, 7 days after the first session. Lower extremity strength was assessed by establishing each subject's 1-RM on the leg press. At the completion of strength testing, power was assessed at 40%, 50%, 60%, 70%, 80%, and 90% of the measured 1-RM. Measurement of power at 6 different relative intensities allowed the examination of the importance of power across a range of values. Subjects were instructed to extend their legs to a point of almost full extension as quickly as possible against the set resistance and then slowly return the pedals to the start position. Three attempts were given at each external resistance with the highest value recorded for analysis to represent the subject's best performance. A 30 to 60 second rest was given between each of the attempts. This protocol was repeated during the third session, 2 to 7 days after the second session to account for possible learning effects involved with strength testing in older adults.[34] The greater of the two strength measures were used for analysis. The power results associated with the higher strength measurement were used for analysis. If a subject had the same strength measurements between the 2 trials, the power testing session with overall greatest power was used for analysis. Strength and power results were normalized to body mass.

Three outcomes measures of power were used to allow the examination of the influence of power across a range of intensities. Overall peak power, power at 40% 1-RM, and power at 90% 1-RM were used for analysis. Power at 40% 1-RM represented power at a low relative intensity and has been found to have a relationship to laboratory walking measures.[24] Power at 90% 1-RM was examined to determine the importance of power at a high intensity on walking performance. The loss of strength and power that takes place during the aging process[19] and due to inactivity and deconditioning[35] may make tasks thought of as low intensity activities, such as walking, more strenuous for older adults because there is less muscle to perform the activity and the muscle that remains has to work at a higher intensity during the activity. This may lead to older adults requiring a higher percentage of their maximal force production to complete these previously low intensities activities. For this reason, it was decided that considering the relationship of power at a high relative intensity to walking behaviors would be an important issue to explore.

Walking Behaviors

The AMP 331 (Dynastream Innovations, Cochrane Alberta, Canada) was used to assess everyday walking behaviors. The AMP 331 is a triaxial accelerometer worn around the ankle in a mesh pouch that uses acceleration data along with the angular position of the shank of the leg to tabulate cadence, determine the length of each step, and the time duration of each step. From this information, gait speed and distance traveled are calculated. The AMP 331 demonstrates high accuracy for distance (94%) and step counts (99%) and low error rate for walking speed (< 2.5%).[36,37] The average number of total steps per day, walking distance (meters) per day, and average walking speed (m/s) per day were determined from 6 full days of wearing the AMP 331. The epoch of the AMP 331 was set at one hour. If subjects did not wear the AMP 331 for a total of 8 hours a day, the data from this day were eliminated from analysis.

At the end of the first session, subjects received the activity monitor, written instructions on how to use the monitor, and a log book to track the types of activities performed throughout the week. During the second session, subjects returned their activity monitor and log book.

Statistical Analysis

All data analyses were performed using SPSS 12.0 for Windows (SPSS Inc. Chicago, Ill). Pearson Correlation Coefficients were calculated first to determine the relationship between measures of strength, power, and walking behaviors. Because previous studies have demonstrated a curvilinear relationship between strength and physical limitations, and power and physical limitations in older adults[22,38] scatter plots were first visually inspected for any signs of a nonlinear relationship between the measures of strength and power to total steps, walking distance, or walking speed. If scatter plots indicated a possible curvilinear relationship, further analysis was performed to determine whether a significant curvilinear relationship was present.

Stepwise multiple regression models were used to determine the relationship between measures of strength and power to walking behaviors and to determine how much of the variance in walking behaviors could be explained through strength and power measures. Three regression models were used with total steps, walking distance, and walking speed serving as dependent variables. Strength, peak power, power at 40% 1-RM, and power at 90% 1-RM were considered as possible independent variables. The significance level for entrance into the regression equation was set at $p < 0.05$ and the significance level for removal was set at $p > 0.10$. Age and sex were considered possible covariates. If age or sex was significant related to total steps, walking distance, or walking speed, they were entered into the model prior to measures of strength or power.

Regression diagnostics were investigated for all models. If a standardized residual was three or more standard deviations from the mean, it was considered an outlier. The influence of each case on the regression equation was examined through Cook's Distance. Cook's Distance measures the extent to which the regression coefficients change when an observation is removed from the model.[39] Cook Distance greater than one indicates that the case is having a large impact on the model and may be misrepresenting the true nature of the relationship between the independent and dependent variables. Cases with Cook's Distance values greater than one were identified as cases that should be considered an outlier.

RESULTS

Mean, standard deviation, and 95% confidence interval values for strength, power, and walking behaviors are displayed in Table 1. Detailed information on reliability between testing sessions for strength and power has previously been published.[33] Generally, high reliability was found between muscle testing sessions (ICC's ranging from 0.87 – 0.99). Four subjects has missing data at 40% 1-RM and one subject had missing data at 50% 1-RM secondary to the lowest amount of resistance the leg press could provide being greater than 40% or 50% of the 4 subjects' 1-RM. Subjects achieved peak power across a range of relative intensities with the mean relative intensity at which peak power occurred equaling 62% of 1-RM.

One subject's walking data was lost due to a computer error and the subject refused to wear the activity monitor for another week. Seven subjects had one day of data eliminated from analysis and one subject had 2 days eliminated due to not wearing the activity monitor for 8 hours during those days. Analysis was performed to determine whether it would be appropriate to use the data for subjects without 6 full days of activity recorded. For the 20 subjects with 6 valid days of data, 2 techniques were undertaken. First, a repeated measures analysis of variance (ANOVA) was performed to determine whether there were significant differences in steps, distance, or speed between days. If the ANOVA demonstrated a significance difference, this would indicate that the walking behaviors differ based on the day and would limit the ability to use data from

Table 1. Results of Outcomes Measures

	Mean ± SD	95% Confidence Interval
Strength (Newtons/kilograms)	15.5 ± 4.0	14.0-17.0
Peak Power (Watts/kilograms)	7.6 ±2.7	6.6-8.6
Power 40% 1-RM (Watts/kilograms)	7.1 ± 2.7	6.1-8.1
Power 90% 1-RM (Watts/kilograms)	5.7 ± 2.4	4.8-6.6
Total Steps	6384.4 ± 2370.8	5521.5-7247.3
Walking Distance (meters per day)	2174.0 ± 898.3	1847.1-2501.0
Walking Speed (meters/second)	0.72 ± 0.17	0.66-0.78
SD – Standard Deviation 1-RM – One repetition maximum		

subjects with less than 6 days of data. Second, intraclass correlation coefficients (ICC) were calculated to determine the consistency between the total steps, walking distance, and walking speed averaged across the first 4 days in comparison to the average of all 6 days. No differences were found between the days 1-6 for steps (F = 1.47, p = 0.21), distance (F = 1.07, p = 0.39), or speed (F = 0.974, p = 0.44). These findings showed that subjects' amount and intensity of walking behaviors between days did not significantly differ. The ICC's ranged from 0.97 – 0.98 indicating that the average values across 4 days were consistent with average values across 6 days. The results of both of these analyses supported including subjects who did not have 6 full days of data in the analysis.

Table 2 presents results from the correlation analysis. Variables of strength and power results showed high correlation indicating that those subjects with high strength also had high power values. This finding is similar to correlation values between strength and power measures previously reported in the literature.[22] Table 2 also lists the correlation between measures of strength, power, total steps, walking distance, and walking speed. Only peak power was significant correlated with total steps. All values of strength and power were correlated with walking distance and walking speed with peak power having the highest correlation. All three values of power had higher correlations with walking distance and walking speed than strength.

Inspection of scatter plots did not indicate the presence of a curvilinear relationship between the strength and power values to total steps, walking distance, or walking speed. Based on this finding, it was determined that further analysis into curvilinear relationships was not warranted.

When stepwise multiple regression analysis was carried out, only one independent variable, peak power, was entered into each of the three models. These findings indicated that peak power had the greatest relationship to total steps, walking distance, and walking speed in comparison to the other independent variables. The other independent variables likely did not enter the models because of the high correlation between the strength and power values (Table 2). Based on this situation, it was decided to carry out separate simple linear regression analysis to determine the relationship between strength and power measures to each measure of walking behavior. Total steps, walking distance, and walking speed were the dependent variables and measures of strength and power were the independent variables. This allowed the calculation of coefficient of determinations (R^2) between each independent variable to each dependent variable and also allowed the investigators to control for any covariance between age and sex to the dependent variables. Twelve simple linear regression models were developed with results showed in Table 3. At no time was age or sex significantly related to total steps, walking distance, or walking speed. One subject's data for walking distance and walking speed was considered an outlier and eliminated from analysis. As was similarly found in the correlation analysis, peak power explain the most variance in the dependent variables and all power values had greater relationships to walking distance and walking speed than strength. Coefficient of determinations are displayed in Figure 2.

DISCUSSION

The results of this study show that lower extremity strength, peak power, power at a low relative intensity, and power at a high relative intensity are all related to everyday walking behaviors in older adults with functional limitations. Of all the measures of strength and power, peak power had the strongest relationship to walking behaviors. While some of the results reflect aspects of other studies in the literature, this is the first study to examine the relationship between strength and power to actual everyday walking behaviors measured with activity monitors.

Subjects with mild to moderate functional limitations were sought for this study to better reflect the population that most health care professional work encounter. Based on the number of chronic health conditions and limitations on the SF-36 physical function subscale, the subjects in the study did meet this criterion. The subjects in this study averaged 6384.4 ± 2370.8 steps per day. This value is comparable to other studies that have reported step counts for older adults with limitations.[40,41]

Based on the findings of previous studies,[24] it was hypothesized that power at a low relative intensity would have the greatest influence on walking behaviors because walking is considered a lower intensity activities. However in this study, peak power consistently explained more of the variance in the walking data than any other measure. One explanation for this finding is because the subjects is this study had mild to moderate functional limitations and likely suffered from sarcopenia, walking was a more strenuous activity. The subject's may have had a loss of their physiological reserve and needed a higher relative intensity of strength and power to ambulate. It should be acknowledged that the investigators did not col-

Table 2. Pearson Correlation Coefficients between Strength and Power Values and Walking Behaviors

	Peak Power	Power at 40% 1-RM	Power at 90% 1-RM	Steps per Day	Walking Distance	Walking Speed
Strength	0.93***	0.93***	0.70***	0.31	0.48**	0.62***
Peak Power		0.98***	0.77***	0.40*	0.61***	0.70***
Power at 40% 1-RM			0.66***	0.29	0.52**	0.62***
Power at 90% 1-RM				0.36	0.59***	0.69***

* p < 0.05
** p < 0.01
*** p < 0.001
Note: Correlation analysis completed with strength and power results normalized to body mass.

Table 3. Simple Linear Regression Models for Strength and Power to Walking Behavior

Variables		B	SE B	ß	R^2
Total Steps as the Dependent Variable					
Constant		3566.38	1704.67		
	Strength	184.15	107.86	0.31	0.10
Constant		378.25	1224.63		
	Peak Power	340.99	152.08	0.40	0.16*
Constant		4999.58	1223.03		
	Power at 40% 1-RM	237.41	160.68	0.29	0.09
Constant		4413.03	1070.50		
	Power at 90% 1-RM	351.73	175.81	0.36	0.13
Walking Distance as the Dependent Variable					
Constant		517.88	594.87		
	Strength	108.22	37.64	0.48	0.23**
Constant		576.75	358.32		
	Peak Power †	201.68	44.28	0.67	0.44***
Constant		870.81	367.04		
	Power at 40% 1-RM	187.40	47.63	0.64	0.41***
Constant		957.28	352.41		
	Power at 90% 1-RM	217.08	57.88	0.59	0.34***
Walking Speed as the Dependent Variable					
Constant		0.33	0.10		
	Strength	0.03	0.01	0.62	0.39***
Constant		0.41	0.07		
	Peak Power	0.04	0.01	0.70	0.50***
Constant		0.47	0.08		
	Power at 40% 1-RM	0.04	0.01	0.62	0.38***
Constant		0.46	0.06		
	Power at 90% 1-RM	0.05	0.01	0.69	0.48***

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
† Indicates that one subject's data were excluded from analysis due to being an outlier

lect any data, such bioelectrical impedance body composition, dual energy X-ray absorptiometry, or hand grip strength,[42-44] that would allow a diagnosis of sarcopenia to be made.

A second reason for the finding about peak power might be that walking behavior in this study was examined outside of a laboratory environment using an activity monitor. In the laboratory setting, walking measures reflect what a person can do, while data collected with an activity monitor measures what the person actually does. This difference is demonstrated when gait speed across a 4 meter distance for the subjects in this study (0.97 ± 0.23 m/s)[33] is compared to their gait speed values from the AMP 331. The Pearson Correlation Coefficient between the two measures of gait speed is r = 0.56 (p = 0.002). This correlation is significant, but the 4 meter gait speed does not entirely explain the gait speed chosen during everyday walking. Factors such as environment, family situations, socio-economical situations, and motivation likely led to the differences. Healthcare professionals should consider these nonphysiological factors, in addition to walking capability, when prescribing walking program. Ultimately, health outcomes are realized via habitual, everyday activity. Incorporating both community and laboratory measures may be an optimal strategy for tracking progress. Certainly, a closer examination of the relationship between walking speed in the community and walking speed in the laboratory is warranted in future studies.

One of the main aims of this study was to see if strength and power were related to everyday walking to the same magnitude as laboratory measures of walking. Since one of the ultimate goals of rehabilitation professionals is to improve community function and

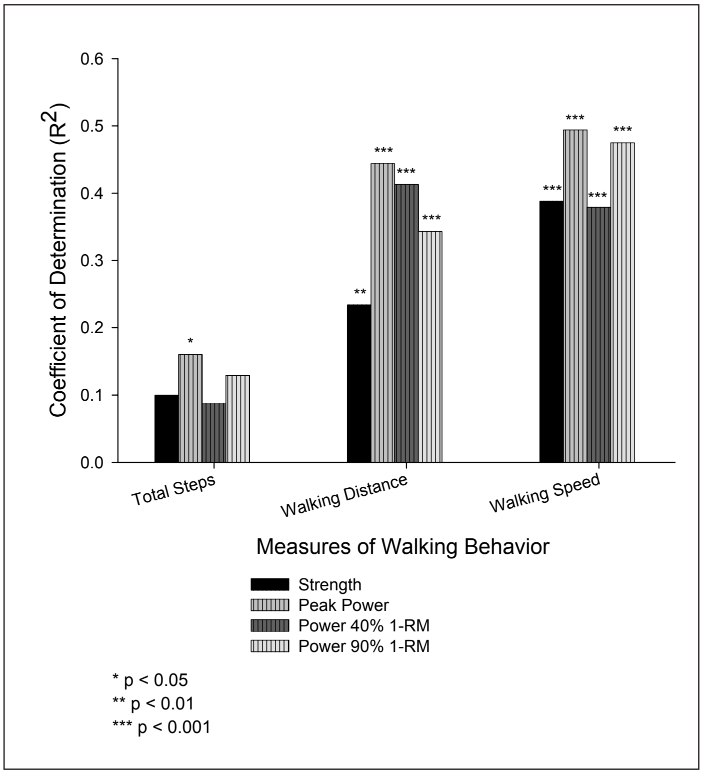

Figure 2. Coefficient of determination for strength and power measurements to walking behavior.

quality of life, these results have meaningful implications. The results of this study demonstrate that lower extremity strength and power may have a stronger relationship to everyday walking behaviors in older adults than laboratory measures of walking. In previous studies, the relationship of power to laboratory walking speed demonstrated R^2 values ranging from 0.26-0.41.[21,24,45] In this study, the R^2 values for power values to everyday walking speed ranged from 0.38-0.50. These results provide further support for the importance of training to increase lower extremity strength and power in older adults.

A Priori it is was determined that stepwise multiple regression analysis would be used to examine the relationships of strength and power to total steps, walking distance, and walking speed. High correlation between measures of strength and power limited our ability to use stepwise regression analysis to understand the relationships between strength and power values to walking behaviors. The decision was made to use simple linear regression instead. One criticism of this technique is that it led to 12 separate analyses performed and increased the risk of Type I error. As was addressed in the previous paragraph, the R^2 values in the significant regression models were equal to or greater than values reported in previous studies. Additionally, the p values for the significant regression models were less than 0.01 in 8 or 9 significant models with 7 of the 9 models having p values equal to or less than 0.001. Based on these factors, we feel that the significant relationships are meaningful and likely not because of Type I error.

The assessment of step counts provides important information on subjects' amount of activity and has become a popular outcome measure for physical activity. However, the analysis of total steps has limitations that need to be considered when studying older adults. Older adults have been shown to have a shorter step length than younger adults.[46] Additionally, older adults who have greater limitations in function demonstrate a smaller step length than older adults who do not have limitations.[47] These studies would indicate that older subjects and those subjects with functional limitations likely take a greater number of steps to cover the same distance in comparison to the younger subjects and those without functional limitations. If total steps was used as the sole outcome measure, older adults with functional limitations may appear to be more active than other subjects, when in fact this may not be the case. These shortcomings of measuring steps in older adults are likely why measures of muscle strength and power had weaker relationships to total steps. While previous studies have found that step counts can distinguish between older adults with different functional abilities,[40,41] the issue of changes in step length should be considered when only examining step counts. The limitation of examining only steps highlights the strengths of the AMP 331 in its ability to measure step length and walking speed.

Since 8 subjects did not have the full 6 days of activity monitor data, analysis was done to see if the measured walking performance across 4 days would be different than performance across 6 days. Previous investigators have stated that an ICC of 0.80 or greater is desirable to demonstrate consistency in measurements across days.[48] Our analysis supported using only 4 days of data. This finding has importance for investigators who use activity monitors with older adults. Measuring activity across a smaller range of days decreases the burden on the subjects and would allow assessment of more subjects in a shorter time period.

The results of this study support the importance of lower extremity strength and power in older adults and the potential of resistance training to have a significant effect on community function. The fact that peak power explained 50% of the variance in walking speed gives the indication that a well designed resistance training program with a focus on power may lead to significant improvements in community walking speed. Since a low walking speed is related to the presence of chronic disease, general mobility limitations, and disability,[49-51] a strength and power training program that leads to improvements in walking speed may then lead to better function and quality of life in older adults. While previous investigators have found improvements in laboratory measures of walking speed through strength training[52,53] and power training,[54] whether these improvements carry over to community ambulation still needs to be explored.

There are limitations associated with this study that need to be stated. First, only 29 subjects were used for analysis and 24 of those were female. The application of these results to the general population of older adults, especially those without functional limitations, needs to proceed with caution. Second, this study used a cross-sectional design and none of these results prove a causal relationship between strength and power to walking behaviors in older adults.

In conclusion, lower extremity strength and power has a positive association to the community walking behaviors of older adults with peak power having the strongest relationship. The prescription of a training program to improve muscle strength and power, along with behavioral interventions that address environment, social, and psychological barriers to activity, should be considered for older adults with functional limitations as a means to improve walking behaviors.

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REFERENCES

1. American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc.* 1998;30:992-1008.
2. American College of Sports Medicine. *ACSM's Guidelines For Exercise Testing and Prescription*. Seventh ed. Philadelphia, Pa: Lippincott Williams & Wilkins; 2006.
3. U.S. Department of Health and Human Services. *Healthy People 2010: Understanding and Improving Health*. 2nd ed. Washington DC: Government Printing Office; 2000.
4. Centers for Disease Control and Prevention. Special focus: healthy aging. *Chronic Dis Notes Reports.* 1999;12:10-11.
5. Nelson ME, Fisher EC, Dilmanian FA, Dallal GE, Evans WJ. A 1-y walking program and increased dietary calcium in postmenopausal women: effects on bone. *Am J Clin Nutr.* 1991;53:1304-1311.
6. MacRae PG, Asplund LA, Schnelle JF, Ouslander JG, Abrahamse A, Morris C. A walking program for nursing home residents: effects on walk endurance, physical activity, mobility, and quality of life. *J Am Geriatr Soc.* 1996;44:175-180.
7. Rooks DS, Kiel DP, Parsons C, Hayes WC. Self-paced resistance training and walking exercise in community-dwelling older adults: effects on neuromotor performance. *J Gerontol A Biol Sci Med Sci.* 1997;52:M161-168.
8. Hakim AA, Petrovitch H, Burchfiel CM, et al. Effects of walking on mortality among nonsmoking retired men. *N Engl J Med.* 1998;338:94-99.
9. Feskanich D, Willett W, Colditz G. Walking and leisure-time activity and risk of hip fracture in postmenopausal women. *JAMA.* 2002;288:2300-2306.
10. Physical activity programs and behavior counseling in older adult populations. *Med Sci Sports Exerc.* 2004;36:1997-2003.
11. Centers for Disease Control and Prevention. US Physical Activity Statistics. Available at: http://apps.nccd.cdc.gov/PASurveillance/DemoCompareResultV.asp?State=1&Cat=1&Year=2005&Go=GO. Accessed August 6, 2007.
12. Simonsick EM, Guralnik JM, Volpato S, Balfour J, Fried LP. Just get out the door! Importance of walking outside the home for maintaining mobility: findings from the Women's Health and Aging Study. *J Am Geriatr Soc.* 2005;53:198.
13. Lexell J, Taylor CC, Sjostrom M. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *J Neurol Sci.* 1988;84:275-294.
14. Young A, Stokes M, Crowe M. Size and strength of the quadriceps muscles of old and young women. *Eur J Clin Invest.* 1984;14:282-287.
15. Sato T, Akatsuka H, Kito K, Tokoro Y, Tauchi H, Kato K. Age changes in size and number of muscle fibers in human minor pectoral muscle. *Mech Ageing Dev.* 1984;28:99-109.
16. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc.* 2002;50:889-896.
17. Evans WJ. What is sarcopenia? *J. Gerontol. A. Biol. Sci. Med. Sci.* 1995;50 Spec No:5-8.
18. Kraemer WJ, Newton RU. Training for muscular power. *Phys. Med. Rehabil. Clin. N. Am.* 2000;11:341-368, vii.
19. Skelton DA, Greig CA, Davies JM, Young A. Strength, power and related functional ability of healthy people aged 65-89 years. *Age Ageing.* 1994;23:371-377.
20. Faulkner JA, Claflin DR, McCully KK. Power output of fast and slow fibers from human skeletal muscles. In: Jones NL, McCartney N, McComas AJ, eds. *Human Muscle Power*. Champaign, Ill: Human Kinetics; 1986:81-94.
21. Bean JF, Leveille SG, Kiely DK, Bandinelli S, Guralnik JM, Ferrucci L. A comparison of leg power and leg strength within the InCHIANTI study: which influences mobility more? *J Gerontol A Biol Sci Med Sci.* 2003;58:728-733.
22. Bean JF, Kiely DK, Herman S, et al. The relationship between leg power and physical performance in mobility-limited older people. *J Am Geriatr Soc.* 2002;50:461-467.
23. Bean JF, Kiely DK, Leveille SG, et al. The 6-minute walk test in mobility-limited elders: what is being measured? *J Gerontol A Biol Sci Med Sci.* 2002;57:M751-756.
24. Cuoco A, Callahan DM, Sayers S, Frontera WR, Bean J, Fielding RA. Impact of muscle power and force on gait speed in disabled older men and women. *J Gerontol A Biol Sci Med Sci.* 2004;59:1200-1206.
25. Sayers SP, Guralnik JM, Thombs LA, Fielding RA. Effect of leg muscle contraction velocity on functional performance in older men and women. *J Am Geriatr Soc.* 2005;53:467-471.
26. Shumway-Cook A, Patla A, Stewart A, Ferrucci L, Ciol MA, Guralnik JM. Environmental components of mobility disability in community-living older persons. *J Am Geriatr Soc.* 2003;51:393-398.
27. Simonsick EM, Guralnik JM, Fried LP. Who walks? Factors associated with walking behavior in disabled older women with and without self-reported walking difficulty. *J Am Geriatr Soc.* 1999;47:672-680.
28. Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Ann Behav Med* 2003;25:80-91.
29. Stewart AL, Hays RD, Ware JE, Jr. The MOS short-form general health survey. Reliability and validity in a patient population. *Med Care.* 1988;26:724-735.
30. Tombaugh TN, McIntyre NJ. The mini-mental state examination: a comprehensive review. *J Am Geriatr Soc.* 1992;40:922-935.
31. Thomas M, Fiatarone MA, Fielding RA. Leg power in young women: relationship to body composition, strength, and function. *Med Sci Sports Exerc.* 1996;28:1321-1326.
32. Earles DR, Judge JO, Gunnarsson OT. Velocity training induces power-specific adaptations in highly functioning older adults. *Arch Phys Med Rehabil.*;82:872-878.
33. Puthoff ML, Nielsen DH. Relationships among impairments in lower-extremity strength and power, functional limitations, and disability in older adults. *Phys Ther.* 2007;87:1334-1347.

34. Salem GJ, Wang MY, Sigward S. Measuring lower extremity strength in older adults: the stability of isokinetic versus 1RM measures. *J Aging Phys Act.* 2002;10:489-503.
35. Thompson LV. Skeletal muscle adaptations with age, inactivity, and therapeutic exercise. *J Orthop Sports Phys Ther.* 2002;32:44-57.
36. Gildenhuys A, MacDonald P, Fyfe K, Stergiou P. Accuracy of a new activity monitor for assessing exercise intensity during walking. *Med Sci Sports Exerc.* 2004;36:S197.
37. Darter BJ, Janz KJ, Puthoff ML, Broffitt B, Nielsen DH. Reliability and accuracy of the AMP 331 for activity monitoring and energy expenditure prediction. *J Phys Activ Health.* 2006;3:277-291.
38. Jette AM, Assmann SF, Rooks D, Harris BA, Crawford S. Interrelationships among disablement concepts. *J. Gerontol. A. Biol. Sci. Med. Sci.* 1998;53:M395-404.
39. Kleinbaum DG, Kupper LL, Muller KE, Nizam A. *Applied Regression Analysis and Other Multivariable Methods*. 3rd ed. Pacific Grove, Calif: Duxbury Press; 1998.
40. Cavanaugh JT, Coleman KL, Gaines JM, Laing L, Morey MC. Using step activity monitoring to characterize ambulatory activity in community-dwelling older adults. *J Am Geriatr Soc.* 2007;55:120.
41. Petrella JK, Cress ME. Daily ambulation activity and task performance in community-dwelling older adults aged 63-71 years with preclinical disability. *J Gerontol Series A: Biological Sci Med Sci.* 2004;59A:264.
42. Rolland Y, Lauwers-Cances V, Cournot M, et al. Sarcopenia, calf circumference, and physical function of elderly women: a cross-sectional study. *J Am Geriatr Soc.* 2003;51:1120.
43. Lauretani F, Russo CR, Bandinelli S, et al. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. *J Appl Physiol.* 2003;95:1851-1860.
44. Payette H, Roubenoff R, Jacques PF, et al. Insulin-like growth factor-l and interleukin 6 predict sarcopenia in very old community-living men and women: the Framingham Heart Study. *J Am Geriatr Soc.* 2003;51:1237.
45. Herman S, Kiely DK, Leveille S, O'Neill E, Cyberey S, Bean JF. Upper and lower limb muscle power relationships in mobility-limited older adults. *J Gerontol A Biol Sci Med Sci.* 2005;60:476-480.
46. Judge JO, Davis RB, Ounpuu S. Step length reductions in advanced age: the role of ankle and hip kinetics. *J Gerontol A Biol Sci Med Sci.* 1996;51:M303-312.
47. Kressig RW, Gregor RJ, Oliver A, et al. Temporal and spatial features of gait in older adults transitioning to frailty. *Gait Posture.* 2004;20:30-35.
48. Baranowski T, de Moor C. How many days was that? Intra-individual variability and physical activity assessment. *Res Q Exerc Sport.* 2000;71:S74-78.
49. Bendall MJ, Bassey EJ, Pearson MB. Factors affecting walking speed of elderly people. *Age Ageing.* 1989;18:327-332.
50. Jylha M, Guralnik JM, Balfour J, Fried LP. Walking difficulty, walking speed, and age as predictors of self-rated health: the women's health and aging study. J *Gerontol A Biol Sci Med Sci.* 2001;56:M609-617.
51. Guralnik JM, Ferrucci L, Pieper CF, et al. Lower extremity function and subsequent disability: consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. *J Gerontol A Biol Sci Med Sci.* 2000;55:M221-231.
52. Holviala JH, Sallinen JM, Kraemer WJ, Alen MJ, Hakkinen KK. Effects of strength training on muscle strength characteristics, functional capabilities, and balance in middle-aged and older women. *J Strength Cond Res.* 2006;20:336-344.
53. Kalapotharakos VI, Michalopoulos M, Tokmakidis SP, Godolias G, Gourgoulis V. Effects of a heavy and a moderate resistance training on functional performance in older adults. *J Strength Cond Res.* 2005;19:652-657.
54. Henwood TR, Taaffe DR. Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. *Gerontology.* 2005;51:108-115.