

Muscular strength and physical function

PATRICIA A. BRILL, CAROLINE A. MACERA, DOROTHY R. DAVIS, STEVEN N. BLAIR, and NEIL GORDON

School of Public Health, University of South Carolina, Columbia, SC 29208, and Cooper Institute for Aerobics Research, Dallas, TX 75230

ABSTRACT

BRILL, P. A., C. A. MACERA, D. R. DAVIS, S. N. BLAIR, and N. GORDON. Muscular strength and physical function. *Med. Sci. Sports Exerc.*, Vol. 32, No. 2, pp. 412–416, 2000. **Purpose:** The purpose of this study was to evaluate the potential association of muscular strength and endurance at baseline with the prevalence of functional limitations at follow-up. **Methods:** Study participants were 3,069 men and 589 women (30–82 yr) who received a clinical examination including a strength evaluation at the Cooper Clinic between 1980 and 1989 and responded to a 1990 mail-back survey. Participants also had to achieve at least 85% of their age-predicted maximal heart rate on a maximal exercise treadmill test and have no history of heart attack, stroke, diabetes, high blood pressure, cancer, or arthritis at their first visit. A strength index composite score (0–6) was calculated using age- and sex-specific tertiles from bench press, leg press, and sit-up tests. Those scoring 5 or 6 were categorized in the high strength group. Functional health status was assessed by responses to questions about the participant's ability to perform light, moderate, and strenuous recreational, household, daily living, and personal care tasks. **Results:** After an average follow-up of 5 yr, 7% of men and 12% of women reported at least one functional limitation. A logistic regression model including age, aerobic fitness, body mass index, and new health problems at follow-up found that, relative to those with lower levels of strength, the odds of reporting functional limitations at follow-up in men and women categorized as having higher levels of strength were 0.56 (95%CI = 0.34, 0.93) and 0.54 (95%CI = 0.21, 1.39), respectively. **Conclusions:** These findings, if replicated in other populations, suggest that maintenance of strength throughout the lifespan may reduce the prevalence of functional limitations. **Key Words:** ACTIVITIES OF DAILY LIVING, FUNCTIONAL LIMITATIONS, FUNCTIONAL STATUS

Most of the research on the benefits of physical activity and health relates aerobic activity or aerobic fitness to some measure of health, often cardiovascular morbidity or mortality (2,3). Previously, our group found an inverse gradient of self-reported functional limitations across both physical activity and aerobic fitness categories in every age group for both men and women, particularly among those over age 55 (12). Considerable evidence suggests that the ability to perform a physical task is determined by a threshold level of muscular strength and endurance (4–6,8). Individuals lacking the requisite strength may not be able to perform various activities of daily living that are important determinants of independence. A decline in functional status is determined at least in part by muscle strength, flexibility, range of motion, physical fitness, and body composition (4,8,10,11,13,15,17). Those who already report some limitations are more likely to develop additional limitations over time (19). The changes leading to functional

limitation do not generally occur suddenly and may have their origins in lifestyle habits developed over many years.

While the incidence of disability rises sharply with age, it is important to study functional limitations among adults of all ages because of the potential to prevent or minimize subsequent disability. However, in contrast to studies of physical activity and aerobic fitness, there is limited information on the association of muscular strength and endurance to functional limitations among relatively healthy adults under age 65. Thus, the purpose of this report is to examine these associations among healthy men and women aged 30–82.

METHODS

Study population. The study subjects were selected from those who received preventive medical examinations at the Cooper Clinic in Dallas, Texas, between 1980 (when the strength measurements were first available) and 1989 (1 yr before the follow-up mail survey). Approximately 70% of the clinic patients reside in Texas; over 80% are college educated and more than 99% are white. The study protocol was approved by the institutional review boards of both the Cooper Institute for Aerobic Research and the University of

South Carolina. Participants were included if they signed a consent form, completed a muscular strength and endurance evaluation, achieved at least 85% of their age-predicted maximal heart rate on a maximal exercise treadmill test, and responded to a 1990 mail-back survey (65% response rate). Additionally, we excluded those under age 30 or those with a history of heart attack, stroke, diabetes, high blood pressure, cancer, or arthritis at their first visit. The study subjects meeting the inclusion criteria consisted of 3,069 men and 589 women between the ages of 30 and 82 yr.

Laboratory assessments. The strength evaluation included a 1RM lift using Universal bench press and leg press machines (Universal Equipment, Cedar Rapids, IA). The test protocol for the bench press had the participant lie on his/her back with the bar of the bench press machine positioned between the nipple and axilla, and the feet were placed flat on the floor or on the bench. Keeping the lower back flat on the bench, arms were extended slowly upward, then slowly brought back to the starting position. The initial load was 70% of body weight; additional weight (5 or 10 lb.) was added depending on the participant's age, gender, and previous physical activity history, and the exercise was repeated until maximum effort was achieved. The test protocol for the leg press had the participant in a seated position with the ball of the foot placed in the crease of the foot plate of the leg press machine. The knee angle was set at 70° by moving the adjustable seat forward or backward. With the lumbar spine placed firmly against the seat back, participants were instructed to slowly extend their legs, then slowly return them to the starting position. Initial load was 100% of body weight; additional weight (5 or 10 lb.) was added depending on the participant's age, gender, and previous physical activity history and the exercise was repeated until maximum effort was achieved. Scores used in analyses were bench press or leg press/body weight ratio. Muscular endurance was measured by a 60-s bent leg sit-up test. The test protocol for the sit-up test had the participant lie on his/her back with knees bent and feet flat on the floor. Hands were placed on the side of the head with fingers placed over the ears. Participants then were instructed to curl up, touching their elbows to their knees and then lower their trunk until the shoulders touched the mat. Participants completed as many sit-ups as possible during 1 min. This test was used because muscular endurance of the rectus abdominus muscles relates to balance and walking.

A muscular strength and endurance index was calculated using a composite score from the bench press, leg press, and sit-up tests. Tertiles were determined for gender and age groups (30–39, 40–49, 50–59, and 60+) for each measure. The first tertile scores were coded as 0 and the second and third tertiles were coded as 1 and 2, respectively. Scores were added for the three tests for a total score ranging from 0 to 6. Individuals scoring 5 to 6 points were assigned to the high strength group and individuals scoring 0 to 4 were assigned to the low strength group.

Maximal graded exercise treadmill testing was completed by all participants, but only those who achieved at least 85% of their age-predicted maximum heart rate were included.

The test protocol is described in detail in earlier reports (2), and total treadmill time (in minutes) is the variable used in analysis. Treadmill time from this protocol is highly correlated with measured maximal oxygen uptake in men ($r = 0.92$) and in women ($r = 0.94$).

Clinical assessments. Other clinical assessments included a thorough preventive medical evaluation that included a personal and family health history, a physical examination, a questionnaire on demographic characteristics and health habits, anthropometry, resting and exercise ECG, blood chemistry tests, and blood pressure measurement. Trained technicians administered these evaluations following a standard manual of procedure. These methods are described in earlier papers (2,3).

Functional health status assessments from 1990 survey. Because these individuals were young and mostly healthy, available functional health measures that were commonly used in the late 1980s were not appropriate for this group. The questions used in the 1990 survey were the result of deliberation from a panel of experts in the area of physical activity and aging. Functional health status was assessed by responses to 10 questions. These questions focused on the participant's ability to perform light, moderate, and strenuous recreational, household, daily living, and personal care tasks. For example, participants responded to the question, "Are you currently physically able to do the following activities? Please circle YES, YES with ASSISTANCE, or NO for each activity. These questions refer to whether or not you can do the activity and not whether you actually do it." (See Appendix A for specific questions on functional status).

A score of zero was assigned for each YES response and a score of one was assigned for each yes with ASSISTANCE or NO response. Individuals scoring one or more were considered to have some functional limitation. Individuals who checked YES with ASSISTANCE or NO to the light or moderate household activities but could perform the strenuous household activities were coded as having no functional limitations.

Other health assessments from 1990 survey. The range of questions on the 1990 mail-back survey also included information on health conditions and the date of first occurrence. We identified as "new health problems" those who reported a physician diagnosis of heart attack, stroke, diabetes, high blood pressure, cancer, or arthritis since their first clinic visit. This item was used as a control variable in the regression analyses.

Statistical analysis. Descriptive statistics (means or percentages) were calculated for all variables by strength group. Logistic regression models using functional limitation (yes or no) as the dependent variable were developed separately for men and women. Independent variables in the models included items from the baseline examination such as strength group (high, low), age, body composition (measured by BMI; weight (kg) divided by height (m)²), and treadmill time (in minutes), as well as new health problems identified at follow-up (yes, no). These variables were chosen because they have the potential to affect the relationship

between strength and functional limitation. The time from the subject's first visit to the 1990 survey was coded as years of follow-up and also included in the model.

Results. The range of follow-up time from the strength evaluation to the 1990 survey was 1–8 yr with an overall average of 5 yr. At follow-up, 7% of men and 12% of women reported functional limitations (unable to perform or required assistance to perform at least one of the activities). As shown in Table 1, weaker men and women had a higher BMI, lower treadmill times, and a higher percentage reported functional limitations than their stronger peers. There were no statistically significant differences between strength groups by age or by the percentage who developed new health problems during follow-up.

The association of strength (measured at baseline) and functional limitations (measured at follow-up) was evaluated using logistic regression. Even though age and the percentage of subjects with new health problems did not vary by strength group, both of these factors are associated with functional limitation and were included in the logistic regression model. After adjusting for age, BMI, treadmill time, new health problems, and follow-up year, men in the high strength group were about half as likely to report functional problems as men in the low strength group (OR = 0.56, 95% CI = 0.34–0.93). The same general relationship between strength and functional limitations was found for women (OR = 0.54, 95% CI = 0.21–1.39), but the results were not statistically significant, probably because of the small sample size (Table 2). Other factors that were statistically significantly associated with functional limitations included older age, lower levels of aerobic fitness (measured by treadmill time), and developing new health problems during follow-up.

Discussion. Functional limitations are an important indicator of quality of life and the preservation of independence in older persons (6,14). Although functional limitations represent a major source of disability for older adults, the problem may stem from patterns of lifestyle behaviors developed during middle age. This analysis was conducted using over 3,000 healthy men and 589 healthy women aged 30–82 at baseline. Only a small number of these individuals

TABLE 2. Logistic regression models for functional limitations in men and women: odds ratios and 95% confidence intervals.

	Men		Women	
	Odds Ratio	95% CI	Odds Ratio	95% CI
High strength group	0.56	0.34–0.93	0.54	0.21–1.39
Age (yr)	1.05	1.04–1.07	1.04	1.00–1.10
BMI	1.03	0.99–1.07	1.04	0.94–1.14
Treadmill time (min)	0.90	0.86–0.93	0.90	0.83–0.98
New health problems	2.14	1.57–2.92	2.72	1.50–4.96
Follow-up years	1.05	0.98–1.12	1.11	0.96–1.27

§ Odds ratio (OR) and 95% confidence intervals (CI) adjusted for all variables listed. New health problems: heart attack, stroke, diabetes, high blood pressure, cancer, and arthritis.

(7% of men and 12% of women) reported any type of limitation after an average follow-up of 5 yr. Compared with those in the low strength group, men and women in the high strength group had a lower prevalence of functional limitations ($P < 0.05$; Table 1). This relationship persisted after adjusting for several possible confounders (age, BMI, treadmill time, and health problems at follow-up). These results also suggest that, in addition to strength, low levels of aerobic fitness at baseline and the development of new health problems during follow-up were also associated with the prevalence of functional limitations at follow-up (Table 2). It is worth noting that treadmill time and muscular strength make independent contributions to the prevalence of functional limitations in this analysis. This is consistent with our previous work (12) but also supports the theory that a threshold level of strength may be required to perform basic activities of daily living and to participate in activities designed to maintain cardiorespiratory fitness (6,9).

Other studies have found that body composition is associated with disability (10,11,15). The effect seemed to be present for both underweight and overweight individuals. In our study the relationship between strength and functional limitations was not affected by body composition, probably because we did not have many individuals who were extremely heavy or extremely light. In other more diverse populations, body composition could play an important role that could not be detected in our study.

While other investigations on strength and function are short-term clinical studies or cross-sectional analyses with few subjects, our study includes objective laboratory assessments of physical fitness and strength, a follow-up study design, and over 3,000 men. One major limitation of our study is the lack of baseline information on functional limitations. To minimize this problem, we selected only those who were free of health problems at baseline (heart attack, stroke, diabetes, high blood pressure, cancer, and arthritis) because these conditions may affect the strength measurements and also may be associated with functional limitation. Additionally, we eliminated all those who (at baseline) could not reach 85% of their age-predicted maximal heart rate on a maximal exercise treadmill test, seeking to ensure that our cohort was relatively healthy and not likely to have pre-existing functional limitations. However, there is still the possibility that some members of our cohort had pre-existing functional limitation.

TABLE 1. Characteristics of men and women by musculoskeletal strength and endurance classification (Means and SD or percentages).

	Men (N = 3,069)		Women (N = 589)	
	High Strength N = 600	Low Strength N = 2,469	High Strength N = 129	Low Strength N = 460
Baseline data				
Age (yr)	45.8 (9.2)	46.1 (8.9)	44.8 (8.1)	44.1 (8.3)
BMI*	24.6 (2.5)	25.8 (3.5)	20.9 (1.7)	22.1 (3.0)
Treadmill time (min)*	23.4 (4.3)	19.6 (4.8)	18.6 (4.2)	14.1 (3.9)
Follow-up data				
% with new health problems	19.2	19.6	16.7	22.9
% with functional problems*	3.2	8.3	4.7	13.5
Follow-up years*	5.1 (2.0)	5.6 (2.2)	4.7 (1.7)	5.2 (2.0)

* Significant difference between strength groups ($P < 0.05$) for both men and women. BMI (Body Mass Index), weight (kg)/height (m)²; new health problems (yes or no); heart attack, stroke, diabetes, high blood pressure, cancer, and arthritis; functional limitations (yes for one or more).

The strength measures used in this study were chosen because of their potential relationship to physical function. However, previous validity and reliability tests of the 1RM bench/leg press and the 60-s maximum sit-up test suggest the possibility of misclassification of some persons (18). Although we tried to minimize this potential bias by combining the scores and taking only the highest third (those scoring 5 to 6) as the high strength group, this remains a limitation of this study.

Other drawbacks of our study included the small numbers of women and the self-report nature of the outcome variable (functional limitations). The high educational level of this group and documented reliability of other self-reported measures, such as hypertension (2), serve to minimize the effect of self-report bias in this population. Additionally, self-reported functional status has been shown to be relatively accurate when compared with performance measures (7). Furthermore, our findings on the overall prevalence of functional limitations and the higher prevalence among women are consistent with other work (16), although the select nature of this population precludes generalizing these findings to other populations.

Although older cohorts have the highest risk of developing disability, the association between muscular strength and endurance and the subsequent prevalence of functional

limitations found in this study indicates that this relationship persists even among middle-aged adults. While most physical activity recommendations conclude that aerobic conditioning activities are required for adults of all ages, until recently strength training was primarily recommended for older adults. Our results support the current ACSM guidelines that encourage all adults, in addition to increasing aerobic physical activity, to include activities that increase muscular strength (1).

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Current address for Dr. Neil Gordon: Center for Heart Disease Prevention, St. Joseph's/Candler Health System, 5356 Reynolds Street, Suite 120, Savannah, GA 31405.

Current address for Dr. Brill: VA Medical Center, Center of Excellence on Healthy Aging with Disabilities, 2002 Holcombe Blvd., Houston, TX 77030.

Address for correspondence: Dr. C. A. Macera, Centers For Disease Control and Prevention, Division of Nutrition and Physical Activity, 4770 Buford Hwy, N.E., Mail Stop K46, Atlanta, GA 30341. E-mail: cam4@cdc.gov.

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APPENDIX A: PHYSICAL FUNCTIONING AND ACTIVITIES OF DAILY LIVING

In this section we would like to find out what activities you are physically able to do. Are you currently able to do the following activities? (Please circle **YES**, **YES with ASSISTANCE**, or **NO** for each activity). Remember that these questions refer to whether or not you can do the activity, and not whether you actually do it regularly.

RECREATIONAL ACTIVITIES

Moderate recreational activities such as leisure bicycling, fishing, ballroom dancing, or volleyball.

Strenuous recreational activities such as jogging, basketball, circuit training, skiing, or tennis.

HOUSEHOLD ACTIVITIES

Light household activities such as cooking, ironing, painting inside, dusting, or making beds.

Moderate household activities such as general carpentry, cleaning, food shopping, mopping floor, vacuuming, or raking.

Strenuous household activities such as digging in garden, mowing, scrubbing floors, shoveling snow, or washing cars.

DAILY ACTIVITIES

Light daily activities such as twisting/bending, reaching overhead/out, grasping with fingers, sitting, or standing.

Moderate daily activities such as lifting/carrying 10 lb., stooping, crouching, kneeling, or prolonged sitting/standing.

Strenuous daily activities such as walking 1/4 mile, climbing 10 stairs with no rest, lifting/carrying 25 lb, or moving large objects such as a heavy chair.

PERSONAL CARE

Moderate personal care activities such as bathing/showing, going to the toilet, dressing, or getting in/out bed/chair/bathtub.

Activities requiring dexterity such as writing, turning keys, buttoning, or opening jars.