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Physical and Performance Measures for the Identification of Mild to Moderate Frailty

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Background. The relative importance and association of factors contributing to physical frailty in elderly persons are unclear.

Methods. Physical measures of upper and lower extremity strength, range of motion, balance, coordination, sensation, and gait were evaluated in relation to scores obtained on a 36-point physical performance test (PPT) in 107 elderly subjects.

Results. Scores on the PPT were significantly associated with the measures of strength and balance, gait, several range of motion values, and sensation. Subjects were also grouped according to score on the PPT as not frail (32–36 points), mildly frail (25–31 points), or moderately frail (17–24 points). ANOVA followed by Bonferroni post hoc analyses were used to examine the relationships of physical measures to this index of frailty. Balance measures, an obstacle course, the Berg scale, the full tandem portion of the Romberg test, and fast gait speed were significantly different among the three groups. Multiple stepwise regression analyses indicated that the strongest combination of variables, explaining 73% of all the variance in the PPT, included obstacle course performance, hip abduction strength, the semitandem portion of the Romberg test, and coordination (pegboard).

Conclusions. Results provide further insight into the relative importance of factors that contribute to frailty and factors that should be considered in treatment planning for the remediation of physical frailty in old adults.

ALTHOUGH there is no universally accepted definition of physical frailty, it is generally agreed that frail older adults have difficulty with such fundamental tasks as dressing, shopping, housework, and ambulation (1,2). Physical frailty is thought to be due to a number of factors, including declines in strength, loss in range of motion, slowness of movement, paucity of movement, poor balance, and reduced muscular and cardiovascular endurance (3–5). In previous investigations, these factors contributing to physical frailty tended to be examined in isolation, and thus their relative importance, or the association of multiple factors, is not clear (3,5,6).

The physical performance test (PPT) described by Reuben and Siu (7) consists of seven or nine functional items that correlate well with degree of disability, loss of independence, and early mortality. Two other items from a battery of tests described by Guralnik and coworkers (8), the chair rise test and the Romberg test for balance, also correlate with nursing home placement and loss of independence. For purposes of this study, we combined the chair rise and Romberg tests (8) with seven items of the PPT (7) to provide an objective assessment of degree of frailty that has been validated (9–11). We also evaluated other tests of balance, strength, speed of movement, flexibility, sensation, endurance, and coordination as markers for frailty based on their correlation with scores on our modified PPT. The purpose of this study was to examine the relationship of multiple physical factors believed to be associated with frailty, including isometric and dynamic strength, range of motion, sensation, coordination, balance, and reaction time with the PPT. It was our belief that understanding the relationship of multiple impairments to frailty will better enable the clinician to develop appropriate treatment strategies for the remediation of frailty.

Methods

Sample

One hundred and seven elderly (>77 years) men and women living in the community who expressed possible interest in an exercise intervention study were recruited. Subjects became interested in the study after exposure to newspaper and radio public service announcements, talks at local community and senior living centers, and flyers in the medical center. Some participants responded to letters mailed directly to age-appropriate individuals in the local community, to word of mouth, or to the urging of concerned family members. Once the study was further explained, potential recruits underwent a screening evaluation for frailty.

Subjects had an average of three chronic medical conditions, with the largest percentage presenting with arthritis or congestive heart failure. Medical conditions were determined by self-report but were confirmed by glucose tolerance testing, physician and nurse examination of all medications taken, and physician screening as part of core testing.

PPT

As part of baseline screening, all subjects underwent a modified physical performance test (Table 1). Each of the nine items on the PPT is worth a maximum of 4 points, for a perfect score of 36.

Table 1. Modified Physical Performance Test Items

1. Book lift. An ∼7-lb book is lifted from waist height to a shelf ∼12 in above shoulder level. Scores are based on the time required to complete the task.
2. Put on and take off a coat. Subjects put on and take off a standard lab coat of appropriate size as quickly as able. Scores are based on the time required to complete this item.
3. Pick up penny. Subjects pick up as quickly as possible a penny that is located ∼12 in in front of the foot. Scores are based on the time required to complete the task.
4. Chair rise. Subjects sit in a chair that has a seat height of 16 in. They then stand fully and sit back down, without using the hands, five times, as quickly as possible.
5. Turn 360°. Participants turn both clockwise and counterclockwise quickly but safely. They are subjectively graded on steadiness and ability to produce continuous turning movement.
6. 50-ft. walk. Subjects walk 25 ft in a straight line, turn, and return to the initial starting place as quickly as possible, safely.
7. One flight of stairs. The time required to ascend 10 steps.
8. Four flights of stairs. Participants climb four flights of stairs. One point is given for each flight of stairs completed.
9. Progressive Romberg test. Subjects are scored according to their ability to maintain a reduced base of support: feet together, semitandem, and full tandem, for a maximum of 10 seconds.

Note: Maximum score is 36; 4 points per item.
Sources: Reuben and Siu (7) and Guralnik and coworkers (8).

Subjects were divided into three groups on the basis of PPT scores to examine differences in physical measures among groups with different degrees of frailty. For purposes of this study, the group with PPT scores ranging from 32 to 36 was considered "not frail," the group with scores ranging from 25 to 32 points was considered to have "mild frailty," and the group with PPT scores between 17 and 24 points was considered to have "moderate frailty." It has been our experience that those scoring below 17 points no longer function independently within the community (unpublished observations).

Physical Measures

Strength.—For testing of the knee extensors and flexors, subjects were seated on a Cybex isokinetic dynamometer with the back supported and hips at 120° of flexion as previously described (12). Tests were performed at 0°, 60°, and 180° per second. For the isometric test, the arm of the dynamometer was fixed at ∼45° of flexion for examination of the quadriceps and at ∼60° of flexion for the knee flexor group. For testing the ankle plantar and dorsiflexors, subjects were placed in the supine position with the hip at ∼45° and the knee positioned at 90° of flexion. Tests were performed at speeds of 0°, 60°, and 120° per second.

Hand-held dynamometry was used for strength testing of the upper extremities and proximal musculature of the lower extremities. The standard break test was used, and two repetitions of each action were recorded. For shoulder flexion, the arm was placed at 90° of sagittal flexion (sitting position) and the Micro-Fet dynamometer was placed on the arm, just above the elbow. For shoulder abduction, the arm was moved to 90° of abduction and resistance was again applied just above the elbow. Elbow flexion was tested while the subject was seated with the arm at the side, the forearm fixed at 90° of flexion, and resistance applied at the wrist. Grip strength was obtained using a Jamar dynamometer, which was adjusted to accommodate for differences in hand size. Hip extension was measured while the subject was prone. One lower extremity was extended toward the ceiling, with the knee in ∼30° of flexion, and the dynamometer was placed on the distal thigh, just above the popliteal fossa. For hip abduction, subjects were in side-lying position with the thigh passively placed in ∼20° of abduction, slight external rotation and hip extension. Once the thigh was positioned, the examiner slowly released the thigh to ensure that the subject could, in fact, hold the test position. If test position was maintained, the dynamometer was placed on the lateral thigh, just above the knee. Abdominals were tested according to the protocol described by Kendall and coworkers (13).

Range of motion.—Range of motion measures were obtained to identify deficits that might impair ability to accomplish functional tasks. Standard goniometric measures were obtained of passive shoulder flexion, shoulder external rotation, straight leg raising (hip flexion with the knee extended), hip internal rotation, knee flexion, and ankle dorsiflexion (14). In addition, trunk rotation was measured while subjects were seated. To accomplish this measure, elbows were flexed to ∼90° and positioned tightly at the side, and a yardstick was placed in the hands. Subjects were asked to turn the trunk as far as possible, and the distance the yardstick rotated from the sagittal plane was measured with the goniometer. The reliability of this method was established during the pilot study that preceded this investigation. In addition to trunk rotation, the distance from the fingertips to the floor was measured after forward bending and side bending. Hip flexor tightness was assessed using the Thomas test (15).

Balance.—Given the variety of balance requirements in daily life, multiple measures of balance (static, dynamic, and weight shift) were obtained. Static balance was obtained by having subjects stand on one leg for a maximum of 30 seconds on each side. No practice sessions were given. In addition, static balance was assessed using the functional reach test as described by Duncan and colleagues (16). This test requires a subject to bring one arm to 90° of flexion and reach forward as far as possible (forward displacement of trunk), arm parallel to a yardstick, without losing balance. The distance reached is recorded in inches. The ability to maintain static balance under conditions of reduced base of support was measured using the Romberg test (8). This staged test requires subjects to balance for 10 seconds in each of three test positions: feet together, semitandem, and full tandem postures. Time spent in each condition (maximum of 10 seconds) was recorded and used in the analyses. Dynamic balance was assessed using a balance beam, obstacle course, and fast gait speed. The balance beam consisted of a board 5.5 in wide, 1.5 in high, and 16 ft long. The time to walk the middle 12 ft of the beam was recorded. The obstacle course consisted of rising from a standard 18-in-high chair (without using arms), walking forward ~6 ft, stepping over a 2 × 2-in obstacle, walking forward another ~6 ft, ascending a 6-in-high curb, turning around, stepping down off the curb, and returning to the chair, as quickly as possible, safely. The obstacle was stepped over on the return trip as well. Finally, the Berg balance test was used because this 14-item examination requires subjects to accomplish static, dynamic, and weight-shifting activities, which can be scored from 0 (unable) to 4 (done safely) according to specific criteria, yielding both a test score and individual item performance data (17).

Gait analysis.—Pressure-sensitive foot switches were applied to the soles of the shoes. The foot switches were embedded in the heel, fifth metatarsal, first metatarsal, and toe regions. Wires from the foot switches were connected to a waist pack containing a module that recorded data in real time from the foot switches. With the aid of computer software (B&L Engineering, Tustin, CA), signals from the waist pack were analyzed to provide temporal measures of gait, including velocity, cadence, stride length, swing and stance time, double support time, and percentages of the gait cycle spent in each phase (18). Two trials for preferred gait speed were obtained. Also recorded were fast gait speed and the presence or absence of critical determinants of the gait cycle (18), namely, heel rise during terminal stance, knee flexion during the loading portion of the stance phase, absent pelvic drop during stance, and 50° or more of knee flexion during the swing phase of gait.

Coordination and speed of reaction.—Upper extremity coordination was assessed using the Purdue pegboard, which requires subjects to pick up one peg at a time from a cup located at the top of the board and place as many pegs as possible into the holes provided, consecutively from top to bottom, in 30 seconds. Two trials were performed, and the average of both trials was used.

Lower extremity reaction time was determined using a driving simulator by having subjects respond to a visual stimulus (green light turning red) by moving the foot from the gas pedal to brake pedal. After the light turned green, a timing switch was activated when the right foot left the accelerator and stopped when the foot hit the brake pedal. Four trials were performed, and the highest and lowest scores were eliminated.

Sensation.—To determine if lack of sensory input was a contributor to functional deficits, two forms of sensory testing were performed. Light touch and pressure sensation were evaluated using Semmes-Weinstein monofilaments (19). Subjects closed their eyes while filaments were pressed against the plantar surface of the great, middle, and small toes, the first, third, and fifth metatarsals, and the heel. The 4.17W (1 g), 5.07W (10 g), and 6.10W (75 g) monofilaments were applied perpendicular to the surface of the skin with enough pressure to bend the filament. Individuals with normal sensation feel the 4.17W filament; those with impaired or absent sensation will sense filaments that are thicker or not feel the filaments at all (19). Those with intact sensation were given a score of 3, those with ability to sense the 5.07W monofilament were given a score of 2, those who could discern the 6.10W monofilament were given a score of 1, and those without sensation were given a zero.

A tuning fork was used to determine vibration perception. Subjects closed their eyes, and a tuning fork vibrating at 128 Hz was placed on the dorsum, first metatarsal head (plantar surface), and heel in random order. If the vibration of the tuning fork was felt for 5 seconds or longer, sensation was recorded as present (score = 1). If the vibration was not felt at all or felt for less than 5 seconds, proprioception was graded as absent (score = 0) (19).

Three physical therapists, including two of the authors, were consistently involved in the testing and did some or all of the measures described. Physical therapists always performed the tests requiring clinical experience and skill, which included hand-held dynamometry, sensation, and range of motion. Two research assistants were involved in data collection for timed measures such as balance (e.g., standing on one leg), gait (application of foot switches; downloading data into the computer), Cybex, and coordination and reaction time. Because reliability is such an important issue, methods for establishing reliability were initiated at the beginning of the study. For the therapists, inter- and intratester reliability was established during the pilot study, but reliability was still assessed continuously. Research assistants were not allowed to engage in any subject testing until reliability was established. Methods to establish inter- and intratester reliability and findings for many of these test items will be presented in a separate paper.

Testing usually took an average of 2.5 hours. To prevent undue fatigue, two sessions were always scheduled, usually 2–5 working days apart. If a third session was needed (judgment made by the physical therapist), it was scheduled accordingly. Typically, some of the strength tests, some of the balance tests, and some of the flexibility tests (no set order) were performed in one session to provide rest periods. Considerable care was taken to ensure the best performance possible on each test and to avoid undue burden on the subject. All testers were blind to individual PPT score.

Statistical Analysis

Initially, Pearson correlational analyses were used to evaluate PPT score and all 110 variables to determine if the physical measures were significantly associated with the PPT. Measures of strength, flexibility, balance, reaction time, pegboard, and gait were analyzed using a one-way analysis of variance (ANOVA), with frailty group (i.e., not frail, mildly frail, and moderately frail) as the independent factor. If group differences existed ($p < .05$), Bonferroni post hoc testing was done to identify the groups that were different. Using the variables that were the most robust in each domain, stepwise multiple regression analyses were done to reveal the combination of variables that best explained the variance in PPT scores.

Results

Subjects averaged 83 ± 4 years of age and had an average score on the PPT of 28 ± 4 out of a possible 36 points.

Thirty-nine individuals (36%) fell into the "not frail" category, with PPT scores of 32 points or above (average score 33.4 ± 0.8); 48 (45%) fell into the "mildly frail" category, with scores from 25 to 31 points (average score 28.8 ± 1.2); and 20 individuals (19%) were classified as "moderately frail," with scores from 17 to 24 points (average score 20.6 ± 1.3). Of the subjects tested, one fourth were men, and each group contained the same proportion of men and women.

Physical Measures

Balance.—Univariate analyses revealed a significant association between PPT score and the Berg test, the obstacle course, functional reach test, the full tandem portion of the Romberg test, and the number of errors made while traversing the balance beam. Time to traverse the balance beam and time standing on one leg were not significantly associated with PPT scores (Table 2).

Gait.—All measures obtained from the assessment of gait were significantly related to PPT score (Table 2).

Table 2. Relationships of Physical Measures With Score on the Physical Performance Test (PPT) for 107 Men and Women With an Average Age of 83 ± 4 years

Domain	Test	*r*	*p*
Balance			
	Obstacle course	−.793	<.005
	Berg test	.710	<.005
	Romberg–full tandem	.600	<.001
	Functional reach	.511	<.005
Gait			
	Preferred gait speed	.528	<.05
	Fast gait speed	.518	<.05
	Cadence	.427	<.005
	Stride length	.443	<.05
	% of gait cycle spent in stance	.487	<.05
	Double stance time	.375	<.001
Range of motion			
	Shoulder flexion	.352	<.05
	Shoulder external rotation	.282	<.05
Strength			
	Knee extension 60°/s	.310	<.05
	Knee flexion 60°/s	.324	<.05
	Knee extension 180°/s	.409	<.05
	Dorsiflexion 120°/s	.205	<.001
	Grip	.279	<.05
	Hip extension	.345	<.05
	Hip abduction	.359	<.001
Coordination and reaction time	None		
Sensation	Semmes-Weinstein heel	.293	<.05
	Tuning fork heel	.294	<.05

Note: Not significant: time to traverse balance beam; one-leg stance time; straight leg raise; trunk rotation; lateral bend; forward bend; knee flexion; ankle dorsiflexion; isometric knee extension and flexion; dorsiflexion at 0°, and 60°/s; plantar flexion 0°, 60°, and 120°/s; shoulder flexion; abduction; elbow flexion; knee flexion 180°s; pegboard; brake test; Semmes-Weinstein metatarsal heads and toes; and tuning fork metatarsal heads, dorsum of foot.

Range of motion.—Univariate analyses on range of motion measures and PPT scores revealed significant differences only for shoulder flexion and external rotation range of motion (Table 2).

Strength.—Approximately half of the isokinetic and isometric dynamometry strength measures were significantly related to total PPT score (Table 2).

Between-group differences in strength were not significant for any of the variables examined. Strength values for hip abduction approached significance ($p = 0.06$), with those in the "not frail" group generating an average of 40 ± 11 lb of force, those in the "mildly frail" group 36 ± 10 lb of force, and those in the "moderately frail" group 28 ± 14 lb of force.

Coordination, reaction time, and sensation.—The association between PPT score and coordination (pegboard) and reaction time was not significant. Sensation at the heel was significantly associated with PPT score (Table 2).

Correlational analyses revealed that many of the physical tests were significantly related to PPT score. ANOVA results also supported significant differences between the three groups for most of the physical measures. However, after applying a Bonferroni correction, only four variables remained significantly different between groups: time to complete the obstacle course, time in the full tandem position (Romberg test), scores on the Berg test for balance, and fast gait speed (Table 3).

Multiple Stepwise Regression Analyses

The combination of variables that best explained the variance in PPT scores was the obstacle course, time in the full tandem position of the Romberg test, hip abduction strength, and coordination (pegboard test), with an R^2 value of 0.727 (Table 4).

Discussion

Results from this study demonstrate that diminished functional capacity, as evidenced by performance on the PPT, is associated with multiple physical factors: static and dynamic balance, declines in strength of some muscle groups, range of motion at selected sites, certain types of sensory information from the periphery, gait speed, and speed of movement. One additional physical factor signifi-

Table 3. Significant Grouping Factors and Values or Times for Each

Groups	PPT 32–36 (*n* = 29)	PPT 25–31 (*n* = 48)	PPT 17–24 (*n* = 20)[†]
Obstacle course (s)	10.1 ± 2.2	13.8 ± 3.2	24.9 ± 10.6
Romberg full tandem (s)	8.9 ± 2.7	5.8 ± 3.9	1.9 ± 3.0
Berg balance test	52.5 ± 2.7	50.1 ± 2.6	45.0 ± 3.9
Fast gait (m/min)	94.0 ± 22.2	81.3 ± 18.8	60.4 ± 18.2

Notes: All values are $\bar{x} \pm SD$. Differences between all three groups were statistically significant ($p \leq .05$) following Bonferroni post-hoc testing. [†]Three subjects in the 17–24 PPT score group were unable to accomplish the obstacle course. Only 6 of 20 could perform any part of the full tandem Romberg test.

Table 4. Multiple Regression Analyses with PPT Score as the Dependent Variable

Variables Entered (Lower Extremity)	R^2 value
Obstacle course	.630
Obstacle + knee extension strength at 60°/s	.634
Obstacle + sensation	.643
Obstacle + Romberg (tandem)	.705
Obstacle + Romberg + hip abduction strength	.718
Obstacle + Romberg + hip abduction + pegboard	.727

cantly related to PPT score, but reported elsewhere (20), is aerobic capacity. These findings strongly indicate that frailty is multidimensional and that evaluation of one domain such as strength does not provide adequate insight into this complex phenomenon. Results also support the observation of Duncan and coworkers, that frailty is better explained by the accumulation of deficits across multiple domains rather than by any specific common deficit (21).

Although most of the categories (e.g., strength, flexibility, gait speed) examined were significantly associated with frailty, balance items were the most strongly associated of all variables examined. Although balance scores were among the most strongly associated, not all tests of balance (e.g., one leg stand) were related to performance on the PPT. Results may indicate that some balance tests are better discriminators of frailty than others, or simply that the sensitivity of some balance items is insufficient to capture frailty. It is also possible that items on the PPT fail to challenge the multiple facets of balance. Although additional study is needed, results strongly indicate that balance is a major determinant of frailty, a finding suggested by others (3–5,22,23).

The association between PPT scores and fast gait speed was significant, even following post hoc testing. It is important to note that those categorized as moderately frail had an average fast gait speed (60.2 ± 18.2 m/min) that was barely as high as the preferred gait speed (62.4 ± 11.7 m/min) for the "not frail" elders. Thus, men and women in the "moderately frail" group were, on average, unable to walk quickly enough to cross the street in the time it takes for the light to change from green to red. Most intersections with a stop light and walk cycle require walking at 75–78 m/min, and clearly those in the "moderately frail" group are not able to walk quickly enough to cross the street safely.

Our findings suggest that isolated measures of strength, flexibility, and coordination are insufficient for the identification of frailty (24,25). Findings also suggest, however, that frailty may be readily identifiable using one simple and quickly performed test—the obstacle course ($r^2 = 0.63$). It is likely that the obstacle course performs well because it challenges multiple domains, including balance and coordination (walking quickly, turning), strength (rising from a chair, stepping up a curb), and range of motion (curb, rising from a chair).

Performance measures capture deficits in strength, speed of movement, coordination, flexibility, and balance (8–11,26). Once functional deficits are identified, however, it would be appropriate to subsequently evaluate the likely physical factors underlying the decline in performance. Identification of the physical contributors to frailty is necessary to provide a basis for treatment. Findings from this study suggest that specific tests for factors such as strength, balance, and range of motion can be selected from a comprehensive battery of tests and yield as much information about a frail individual as the complete test battery.

It is common for a frail individual to exhibit deficits in many or all domains of physical measures. Thus, another reason for combining performance tests with physical measures is to determine the most important treatment strategies. Results indicate that the treatment of frailty should incorporate strategies for the remediation of all the likely deficits in strength, balance, range of motion, gait, speed of movement, and coordination. There is evidence to indicate that all of these clinical problems are modifiable, even in an older adult population (27–29). Thus, frailty should be a treatable problem, given the correct approach.

Of all the range of motion measures, only shoulder flexion and external rotation were significantly associated with PPT scores, but this finding may be misleading. Only two of the PPT items, placing a book on a shelf overhead and putting on and taking off a coat actually challenged end range of motion, and only for the upper extremities. Thus, range deficits in the lower extremities did not emerge as being significantly associated with PPT scores because the PPT does not challenge end range of the lower extremities. If large excursions in range of motion were required by the PPT, it is probable that the significance of lost range in the trunk and lower extremities would be more apparent. Most of the subjects in this study, for example, do not have enough trunk rotation to check the blind spot for driving.

Findings from our laboratory support a strong association between aerobic capacity ($\dot{V}O_2$max) and preferred walking speed (20). In this current examination of frailty, fast gait speed was more highly associated with PPT score than preferred walking speed; it is likely that fast gait is more closely associated with aerobic capacity than preferred gait speed. This should be substantiated in future studies.

The linear association between the time to complete the obstacle course and PPT score was the strongest of all values examined ($r = -0.793$). The combination of the obstacle course, the tandem portion of the Romberg test, hip abduction strength, and the pegboard explained 73% of the variability in PPT scores. Although highly significant, this finding seems to indicate that there are other factors not accounted for that are associated with frailty (e.g., cognition, depression, poor vision, poor hearing, pain, and other comorbidities). Although this study was a comprehensive examination of the physical elements of frailty, there is more to physical decline than physical variables alone.

In this study, physical factors were identified as associated with mild to moderate frailty. It is possible that further examination of severely compromised frail individuals, those who require assisted living or are homebound, will reveal a different pattern of involvement. It may be that variables that emerged as the most important for the mild and moderately frail will emerge as less strongly associated with more severe frailty. Further testing of a more involved elderly population is needed.

In summary, this study examined numerous physical factors believed to be associated with physical frailty. We found that frailty was associated with declines in multiple domains. Nearly three-fourths of the variance in frailty was accounted for by performance on an obstacle course and measures of balance, strength, and coordination. Because these factors are potentially modifiable, it seems likely that the incidence of frailty in old age could be reduced through appropriate exercise interventions to prevent and possibly treat frailty. The type of exercise program that will be most beneficial remains to be determined but is likely to include balance activities, resistance training, and endurance types of exercise.

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