Interrelationships Among Disablement Concepts

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Background. Understanding interrelationships among disablement concepts is critical to the design of future disability treatment and prevention interventions.

Methods. This study uses cross-sectional data to examine the relationships among physiologic impairments, functional limitations, and disability in a moderately disabled sample of 207 community-dwelling older adults.

Results. As hypothesized, the data revealed statistically significant curvilinear relationships of upper and lower extremity strength and balance with mobility in this older sample. Multivariate analyses further clarified the hypothesized causal mechanism among the disablement concepts by demonstrating that most of the association of muscle strength and balance with disability was through the intermediary role of mobility limitations.

Conclusions. The findings from this study highlight the value of clinical trials that focus on prevention or treatment of mobility limitations as a means of preventing disability; our findings underscore the need for future research that examines the effects of other variables believed to influence disablement in late life.

Prevention of disability has become a key objective in gerontology and geriatrics (1–4). The disablement process as defined by Nagi (5,6) describes a progression from physiologic impairments (an organ or body system abnormality) to functional limitations (restrictions in basic physical or cognitive performance) to disability (cessation or restriction in carrying out basic and instrumental activities of daily living (ADLs) and other social roles). An important application of this model is its use in identifying health states that are predictive of future disability and responsive to interventions that can prevent or delay the onset and progression of disability and loss of independence with increasing age (4,7–14).

While previous research has established a consistent positive association between skeletal muscle strength (a physiologic impairment) and physical functioning (3,9,15–18), several important limitations remain to be addressed.

Many investigators continue to treat the strength–physical function relationship as linear (11,16,19) despite growing evidence supporting Buchner and deLateur’s thesis that the relationship between skeletal muscle strength and physical functioning can best be characterized as curvilinear (3,15,20). The identification of a threshold in the association between skeletal muscle strength and physical function has important clinical implications, as it would allow the identification of a minimum level of strength necessary for maintaining or recovering function and would help identify specific target groups of weak individuals who might experience disproportionate and sizable gains in function from interventions. More data are needed that provide evidence of a minimum level of muscle strength above which an increase in physiological capacity does not translate into a clinically important improvement in function (9).

Another limitation in previous research is the failure to distinguish between Nagi’s concept of functional limitation (i.e., the individual’s capacity to perform basic physical tasks such as walking) and physical disability (i.e., the individual’s typical behavior in carrying out daily activities and social roles) (15,21). Investigators either ignore the distinction between an individual’s function and physical disability or, at best, assume that the impact of skeletal muscle strength on disability behavior is mediated through the association of strength with functional limitations. The way in which muscle strength relates to disability behavior has not been well described nor is the relationship between functional limitations and disability well understood, although some longitudinal data are beginning to emerge (7).

And finally, while some evidence is available on the relationship of balance ability (another physiologic impairment) and physical function (22), most investigators also have assumed this relationship to be linear. Whether or not Buchner and deLateur’s theoretical argument (15) of a curvilinear relationship between skeletal muscle strength and physical function applies to other impairments, such as balance, remains to be more fully explored.

The purpose of this study, therefore, was to address several of the shortcomings in existing literature. Building on Buchner and deLateur’s seminal work in this area, and Nagi’s disablement model, we hypothesized that:

- the relationship between upper and lower extremity muscle strength and mobility in this sample would be positive and curvilinear;
- the relationship between balance and mobility would be positive and curvilinear;
- the relationship between mobility and disability behavior would be negative and curvilinear.
• the relationship between skeletal muscle strength and disability behavior would be mediated through mobility; and
• the relationship between balance and disability behavior would be mediated through mobility.

Figure 1 illustrates the hypothesized relationships among these disablement variables as specified by the Nagi disablement model. A clearer understanding of the relationships among the disablement concepts can be useful in designing more effective interventions for the prevention of late life disability.

METHODS

Subjects

Data used for these analyses were baseline values on 207 older adults enrolled in an exercise intervention study conducted by the Edward R. Roybal Center for Research in Applied Gerontology at Boston University. Subjects were community-dwelling volunteers between the ages of 60 and 94 years. To participate, subjects had to report limitations in one or more of nine physical activities listed in the physical function scale of the short-form health survey SF-36, which included moderate activities, lifting or carrying groceries, climbing several flights of stairs, climbing one flight of stairs, bending, kneeling, stooping, walking more than a mile, walking several blocks, walking one block, and bathing or dressing oneself (23). Exclusion criteria were self-reported medical conditions including kidney failure requiring dialysis, recent cancer with ongoing medical treatment, uncontrolled diabetes, uncontrolled seizures, any recent fractures, regular use of a wheelchair, legally blind, current fainting spells, dizzy spells, and sudden loss of coordination, report of other current medical conditions that would not allow them to exercise, and concurrently receiving rehabilitation services. Subjects were also excluded if their regular physician identified contraindications for their participation in a strength training study. The New England Research Institutes, the Massachusetts General Hospital, and the Boston University Investigation Review Committees approved all protocols.

Of the 826 community-dwelling older persons contacted for this study, 175 (21%) were too ill to participate or were excluded from the study for other health reasons. Eighty-four (10%) were excluded because they were nondisabled, 34 (4%) were excluded because of language difficulty, and 27 (3%) were excluded for various other reasons unrelated to the program. Of the remaining 506 eligible subjects, 215 (42%) were randomized into the study, and the remainder refused to participate for a variety of reasons. Of those who were randomized, 207 had sufficient baseline data to be included in these analyses.

Measurement Protocols

The following protocols were administered to all subjects during a baseline home visit.

Impairments.—Isometric strength of three major upper and three major lower extremity muscle groups and one measure of balance were administered to assess impairment.

Muscle strength.—Isometric strength measurements were performed using a hand-held dynamometer (Nicholas Dynamometer, Lafayette Instruments, Lafayette, IN) to assess the motions of shoulder abduction and flexion, elbow extension, hip abduction, hip extension, and knee extension. Calibration was performed prior to testing each subject. We adapted for in-home testing standardized protocols for manual muscle testing as described by Smidt (24) and Andrews et al. (25). The right leg and arm were tested unless medical conditions (e.g., pain, previous surgery, or injury) prohibited using that side. All joint positioning was determined with a fixed goniometer. Subjects were placed into position and allowed to practice the test prior to measurement. The last two of three trials were recorded as test results and then averaged. The tester positioned herself so that her forearm and the dynamometer were held perpendicular to the muscle group tested.

Shoulder abduction and flexion.—Subjects sat in chairs with their backs supported, feet flat on the floor, and their shoulders being measured in 0° of flexion, neutral abduction/adduction/rotation, elbows in full extension, and forearms in neutral supination and pronation. The dynamometer was positioned on the lateral arm, 3 inches...
above the lateral condyle. The untested arm was positioned in the subject's lap.

**Elbow extension.**—From the seated position described above, the arm being tested was positioned in 90° of shoulder flexion and 90° of elbow flexion with the forearm in neutral. The dynamometer was positioned on the posterior forearm just above the ulnar styloid process. The tester stabilized the limb by supporting the posterior arm from underneath. The untested arm was positioned in the subject's lap.

**Hip abduction.**—Subjects were seated as above with the knees flexed to 90° and hips in 90° flexion, neutral abduction/adduction/rotation. A pillow was used to support the lumbar spine as needed to maintain the testing position. Hands were positioned in the subject's lap. The dynamometer was positioned on the lateral thigh 3 inches above the lateral supracondyles.

**Knee extension.**—Subjects were repositioned in the chair so the untested foot was flat on the floor and the tested knee positioned in 60° flexion. The subject's heel position on the floor was marked with tape to ensure consistent measurement among the three trials. The dynamometer was placed on the anterior aspect of the tibia, just above the malleoli.

**Hip extension.**—Subjects were standing, holding onto the back of the chair with their legs in 0° of hip and knee extension, hips in neutral abduction/adduction/rotation. The dynamometer was placed on the posterior thigh 3 inches above the posterior crest of the knee joint.

**Balance.**—The functional reach protocol was chosen as an indicator of dynamic aspects of balance. The functional reach protocol we used was a modified version of the test as described by Duncan et al. (26). Our testing protocol differed in three ways from Duncan's protocol: (a) we standardized the base of support between subjects, (b) each subject's heels maintained contact with the floor during the functional reach test, and (c) one examiner both guarded and measured each subject simultaneously. Subjects stood without shoes on a mat. The leg that was strength-tested was positioned closest to the wall. Subjects were instructed to reach forward as far as possible without moving their feet. The movement was demonstrated by the tester and practiced once by the subject prior to two recorded trials. The reach measure was the difference of these two measurements.

**Functional limitation.**—Mobility was assessed with the timed "Up-and-Go" test (27). A straight-backed chair with or without arms was placed 10 feet from a wall. Because testing was performed in each subject's home, the chair used for this test was not standardized for all subjects. At the command "Go," the subject rose from the chair, walked to the wall, turned around, returned to the chair, and sat down. Assistive devices were used as needed. One practice trial and two recorded trials were performed with time to complete the task recorded. The two recorded times were averaged.

**Disability.**—The short-form Sickness Impact Profile (SIP68) was used to assess disability (28). Each item in the SIP is assigned a weight that reflects the relative severity of limitation implied by each statement (29). In this analysis, the total SIP summary score and two subscales were used to assess disability. The weights of the items a person checked were summed; each SIP scale ranges from 0 to 100, where 0 indicates no disability and 100 reflects total disability. The Basic Physical Disability subscale describes behavior that reflects restrictions in an individual's basic physical activities, e.g., walking, climbing stairs, self care. The Instrumental Physical Disability subscale describes the extent to which a person performs several instrumental ADL tasks, e.g., shopping, house cleaning (28). Good test-retest reliability (r = .90) of the SIP68 and its subscales has been demonstrated in an older adult population (28).

### Statistical Analysis

All strength measures were first normalized by dividing the absolute strength measurement by the person's height in meters and weight in kilograms. We created summary scores of upper and lower muscle strength to use in place of the five individual strength measures because the individual and summary strength scores were highly correlated with each other (r = .79-.96). Because of these high correlations, and because Brown et al. (16) found that summing strength scores gave a statistically better model of the relationship between muscle strength and a functional task than using individual scores, we decided to use summary scores.

In the first part of the analysis, we examined the shape of the relationship of normalized upper extremity strength, normalized lower extremity strength, and balance to mobility. For each of the three independent variables, we fit two linear regression models with mobility as the dependent variable: one model that was linear in the independent variable, and one that was quadratic. If the quadratic term was significant at the .05 level, the quadratic model would be preferred over the linear model. Because the mobility measure was skewed, we used the negative inverse transform (-1/mobility) as the dependent variable to obtain normally distributed residuals that was quadratic. If the quadratic term was significant at the .05 level, the quadratic model would be preferred over the linear model. Because the mobility measure was skewed, we used the negative inverse transform (-1/mobility) as the dependent variable to obtain normally distributed residuals (30-31). To avoid problems with collinearity when including a term and its square, the independent variables were centered by subtracting the mean value from each subject's actual value of the independent variable (32). These models were adjusted for age and gender. To provide a graphical presentation of the results, scatterplots of the data were created, with superimposed curves showing predicted values from quadratic models unaadjusted for age and gender. Two-dimensional plots did not allow us to show models adjusted for age and gender.

In the second part of the analysis, we examined the relationship of mobility, normalized upper extremity strength, normalized lower extremity strength, and balance to disability scores from the overall SIP (total disability) and its subscales for Basic Physical Disability and Instrumental Physical Disability. Because there were a large number of subjects with a zero score (no disability) on the SIP and especially on its subscales, this was done in two stages: logistic regressions for the presence of any disability, and linear regressions for the degree of disability, among those subjects with any disability.

To investigate whether mobility, strength, and balance were related to the presence versus absence of disability,
and whether these effects of strength and balance were mediated by mobility, we fit a series of logistic regression models where the dependent variable was coded 0 for subjects with no disability, and 1 for subjects with disability. All models were adjusted for age and gender. Again, we used the negative inverse transform of mobility, rather than the measure on its original scale, because of skewness. Model A included the transformed mobility term, to see whether it had a significant relationship to the presence of disability when adjusting only for age and gender. Model B included upper extremity strength, and Model C included upper extremity strength and mobility. If upper extremity strength were significantly related to disability in Model B, but not in Model C, while the mobility term was significant, this would be evidence in favor of mobility mediating the effect of upper extremity strength on disability. If the strength coefficient became closer to zero but was still significant, this would be evidence of partial mediation. Models D and E, and Models F and G, can be used in the same way to see whether lower extremity strength and balance, respectively, are related to the presence of disability and whether the relationship is mediated by mobility limitations.

To investigate whether mobility, strength, and balance were related to the degree of disability among subjects with any disability and whether these effects of strength and balance were mediated by mobility, we fit a series of linear regression models where the dependent variable was the natural logarithm of the degree of disability. Logarithms were used because the disability measures were skewed. These models are similar to Models A through G mentioned previously, and are interpreted in a similar way. To provide a graphical presentation of the relationship between mobility and degree of disability, scatterplots of the data were created, with superimposed curves showing predicted values from models with mobility as the only independent variable.

**Results**

Background characteristics of the sample are summarized in Table 1. The sample was predominantly female (77%), White (93%), with a mean age of 75 years (range = 60–94 years). Mean muscle strength (kgs force) ranged from 8.4 kgs for hip abduction to 13.8 kgs for knee extension. Although 85% of our sample reported some degree of disability (as measured by a total SIP score > 0), it was on the less disabled end of the scale (mean SIP = 9.8). Nonetheless, the sample did display a range of functional disability with 60.9% reporting some difficulty in three or more functional areas, 21.1% in two areas, and 18% in one of the nine physical function items on the SF36.

**Relationship of impairments to functional limitation.**—

We report first on the observed association between upper and lower extremity strength and balance with mobility limitations. When adjusted for age and gender, mobility improved significantly with increasing relative upper and lower extremity strength and with increasing balance (Table 2). Mobility was associated with advanced age but not with gender in models including strength or balance variables.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Linear Model</th>
<th>Quadratic Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linear Term</td>
<td>R²</td>
</tr>
<tr>
<td>Upper extremity strength</td>
<td>−19 (± .03)**</td>
<td>.2906</td>
</tr>
<tr>
<td>Lower extremity strength</td>
<td>−12 (± .01)**</td>
<td>.3548</td>
</tr>
<tr>
<td>Balance</td>
<td>−0.0601 (± .0005)**</td>
<td>.3389</td>
</tr>
</tbody>
</table>

Note: Negative inverse of the mobility variable, all models adjusted for age and gender.

*p < .05; **p < .01.
As hypothesized, the estimated association of both upper and lower extremity strength with mobility was curvilinear (Figures 2 and 3). As expected, the steepest part of the curves was at the lower end of the strength scale with a progressive flattening of the curve at higher levels of muscle strength. The existence of this curvilinear relationship was confirmed in regression analyses where the quadratic terms of both upper and lower extremity strength values were significant ($p < .01$) in models controlling for age, gender, and the linear strength variable (Table 2). This finding shows that while muscle strength is important to mobility, there is a threshold above which additional muscle strength does not contribute much to improved performance time.

A positive curvilinear relationship between balance and mobility was observed controlling for age and gender in the model ($p < .05$). The graph of the estimated relationship (Figure 4) suggested that a curvilinear association between balance and mobility was present and was confirmed by the quadratic term in the regression analysis, which attained statistical significance ($p < .05$).

**Relationship of functional limitation to disability.**—As hypothesized, mobility was a statistically significant predictor of the presence or absence of overall disability, basic physical disability, and instrumental physical disability, adjusting for age and gender. (See Model A in Tables 3A, 3B, and 3C.) The form of the association between mobility and degree of disability, among those subjects with disability, is shown in Model A in Tables 4A, 4B, and 4C, and is illustrated in Figures 5–7.
The relationship of impairments to disability.—To better understand the nature of the relationship between different impairments and disability, we examined the ability of muscle strength and balance to predict the presence of disability and the degree of disability, with and without controlling for mobility in the model. Upper and lower extremity strength and balance variables were all significantly related to the presence of disability, when adjusted for age and gender. (See Models B, D, and F in Tables 3A, 3B, and 3C.) When mobility was also included in the logistic regression models, the association of strength and balance with the presence of disability was attenuated. (See Models C, E, and G in Tables 4A, 4B, and 4C.)

Similarly, upper and lower extremity strength and balance variables were all significantly related to the degree of disability, when adjusted for age and gender. (See Models B, D, and F in Tables 4A, 4B, and 4C.) When mobility was also included in the linear regression models for degree of disability, the association of strength and balance with degree of disability was largely attenuated. (See Models C, E, and G in Tables 4A, 4B, and 4C.)

**DISCUSSION**

This investigation contributes several important findings about the interrelationships among physiologic impairments, functional limitations, and disability in a sample of community-dwelling older persons. Upper and lower extremity muscle strength and balance were positively related to mobility, as hypothesized, these relationships were curvilinear. Moreover, as hypothesized, declining levels of muscle strength and balance were related to the presence and degree of disability through their effect on mobility. Mobility predicted the presence of disability in this sample; furthermore, it showed a curvilinear relationship with severity of disability. These results provide consistent evidence to support and extend Buchner and deLateur’s basic thesis that...
observed relationships between upper and lower extremity strength and function in older persons can best be characterized as curvilinear associations. Our analyses demonstrate a specific curvilinear relationship between upper and lower extremity strength with one specific functional threshold for upper and lower extremity strength that are at greatest risk of developing mobility limitations and subsequent disability.

Physical tasks are likely to vary in the amount of muscle strength required to accomplish a task, and associations between muscle strength and generalized functional abilities are less likely to be useful in future research than very specific characterizations. Climbing stairs, for example, is likely to require substantial lower extremity strength, whereas lifting a pot from a stove to a table is likely to require primarily upper extremity strength and much less lower extremity strength. Sonn et al. (9), for example, have recently estimated critical levels of knee extensor strength to predict onset of instrumental activities of daily living (IADL) disability over a 6-year period in a sample of 70-year-old men and women. 

\[ \text{Model A: Upper extremity strength} \]
\[ \text{Model B: Lower extremity strength} \]
\[ \text{Model C: Balance} \]
\[ \text{Model D: Age} \]
\[ \text{Model E: Male} \]
\[ \text{Model F: Intercept} \]
\[ \text{Model G: -I/(Mobility)} \]

\[ \text{Table 4A. Linear Regression Models of Associations Between Mobility, Strength, and Balance} \]

<table>
<thead>
<tr>
<th>Model</th>
<th>Intercept</th>
<th>Male</th>
<th>Age</th>
<th>-I/(Mobility)</th>
<th>Upper extremity strength</th>
<th>Lower extremity strength</th>
<th>Balance</th>
<th>R-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.37 (±0.79)**</td>
<td>0.07 (±0.14)</td>
<td>-0.00 (±0.01)</td>
<td>27.50 (±2.76)**</td>
<td>-8.12 (±1.32)**</td>
<td>-5.00 (±0.69)**</td>
<td>-0.13 (±0.02)*</td>
<td>.3852</td>
</tr>
<tr>
<td>B</td>
<td>1.41 (±0.78)</td>
<td>0.31 (±0.18)*</td>
<td>0.02 (±0.01)</td>
<td>23.55 (±2.98)**</td>
<td>-3.88 (±1.25)*</td>
<td>-2.43 (±0.71)**</td>
<td>-0.03 (±0.02)</td>
<td>.2063</td>
</tr>
<tr>
<td>C</td>
<td>4.40 (±0.77)*</td>
<td>0.24 (±0.15)*</td>
<td>0.00 (±0.01)</td>
<td>22.10 (±3.11)**</td>
<td>0.02 (±0.01)*</td>
<td>0.00 (±0.01)</td>
<td>-0.01 (±0.01)</td>
<td>.4176</td>
</tr>
<tr>
<td>D</td>
<td>1.62 (±0.76)*</td>
<td>0.02 (±0.16)</td>
<td>0.02 (±0.01)*</td>
<td>25.72 (±3.21)**</td>
<td>0.00 (±0.01)</td>
<td>0.00 (±0.01)</td>
<td>-0.01 (±0.01)</td>
<td>.2554</td>
</tr>
<tr>
<td>E</td>
<td>4.29 (±0.77)*</td>
<td>0.09 (±0.14)</td>
<td>0.00 (±0.01)</td>
<td>4.72 (±0.74)**</td>
<td>0.01 (±0.01)</td>
<td>0.01 (±0.01)</td>
<td>-0.01 (±0.01)</td>
<td>.4244</td>
</tr>
<tr>
<td>F</td>
<td>2.96 (±0.96)</td>
<td>0.00 (±0.17)</td>
<td>0.00 (±0.01)</td>
<td>4.70 (±0.85)**</td>
<td>0.00 (±0.01)</td>
<td>0.00 (±0.01)</td>
<td>-0.01 (±0.01)</td>
<td>.1609</td>
</tr>
<tr>
<td>G</td>
<td>1.10 (±0.01)</td>
<td>0.07 (±0.14)</td>
<td>0.01 (±0.01)</td>
<td>3.39 (±0.60)</td>
<td>0.01 (±0.01)</td>
<td>0.01 (±0.01)</td>
<td>-0.01 (±0.01)</td>
<td>.3894</td>
</tr>
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\[ \text{Table 4B. Linear Regression Models of Associations Between Mobility, Strength, and Balance} \]

<table>
<thead>
<tr>
<th>Model</th>
<th>Intercept</th>
<th>Male</th>
<th>Age</th>
<th>-I/(Mobility)</th>
<th>Upper extremity strength</th>
<th>Lower extremity strength</th>
<th>Balance</th>
<th>R-square</th>
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<tbody>
<tr>
<td>A</td>
<td>5.51 (±0.65)**</td>
<td>-0.13 (±0.13)</td>
<td>-0.01 (±0.01)</td>
<td>21.44 (±2.40)**</td>
<td>-6.09 (±1.07)**</td>
<td>-3.90 (±0.56)**</td>
<td>-0.11 (±0.02)</td>
<td>.3496</td>
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<tr>
<td>B</td>
<td>3.21 (±0.63)**</td>
<td>0.10 (±0.15)</td>
<td>0.01 (±0.01)</td>
<td>18.29 (±2.65)**</td>
<td>-2.74 (±1.06)**</td>
<td>-2.04 (±0.59)**</td>
<td>-0.04 (±0.02)</td>
<td>.1870</td>
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<tr>
<td>C</td>
<td>5.45 (±0.64)**</td>
<td>-0.01 (±0.13)</td>
<td>-0.00 (±0.01)</td>
<td>16.61 (±2.70)</td>
<td>-0.39 (±0.12)</td>
<td>-0.15 (±0.14)</td>
<td>-0.13 (±0.12)</td>
<td>.3762</td>
</tr>
<tr>
<td>D</td>
<td>3.39 (±0.60)**</td>
<td>-0.12 (±0.13)</td>
<td>0.01 (±0.01)</td>
<td>18.45 (±2.75)**</td>
<td>-0.01 (±0.01)</td>
<td>-0.12 (±0.12)</td>
<td>-0.11 (±0.12)</td>
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<td>E</td>
<td>5.36 (±0.63)**</td>
<td>-0.11 (±0.12)</td>
<td>0.00 (±0.01)</td>
<td>5.99 (±0.68)**</td>
<td>-0.15 (±0.14)</td>
<td>-0.13 (±0.12)</td>
<td>-0.15 (±0.12)</td>
<td>.4176</td>
</tr>
<tr>
<td>F</td>
<td>4.72 (±0.74)**</td>
<td>-0.00 (±0.01)</td>
<td>0.01 (±0.01)</td>
<td>4.70 (±0.85)**</td>
<td>-0.12 (±0.12)</td>
<td>-0.11 (±0.12)</td>
<td>-0.11 (±0.12)</td>
<td>.2554</td>
</tr>
<tr>
<td>G</td>
<td>4.70 (±0.85)**</td>
<td>-0.01 (±0.01)</td>
<td>0.00 (±0.01)</td>
<td>4.70 (±0.85)**</td>
<td>-0.11 (±0.01)</td>
<td>-0.12 (±0.12)</td>
<td>-0.11 (±0.12)</td>
<td>.4244</td>
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</table>

\[ \text{Table 4C. Linear Regression Models of Associations Between Mobility, Strength, and Balance and Degree of Instrumental Physical Disability Among Those With Some Basic Physical Disability; Linear Regression Coefficient ± Standard Error} \]

<table>
<thead>
<tr>
<th>Model</th>
<th>Intercept</th>
<th>Male</th>
<th>Age</th>
<th>-I/(Mobility)</th>
<th>Upper extremity strength</th>
<th>Lower extremity strength</th>
<th>Balance</th>
<th>R-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.72 (±0.97)**</td>
<td>-0.03 (±0.21)</td>
<td>-0.01 (±0.01)</td>
<td>14.97 (±3.64)**</td>
<td>-5.28 (±1.70)**</td>
<td>-3.45 (±0.97)**</td>
<td>-0.07 (±0.03)</td>
<td>.1927</td>
</tr>
<tr>
<td>B</td>
<td>3.50 (±0.91)</td>
<td>0.19 (±0.23)</td>
<td>0.00 (±0.01)</td>
<td>12.17 (±3.94)**</td>
<td>-3.04 (±1.76)**</td>
<td>-4.82 (±2.17)**</td>
<td>-0.01 (±0.03)</td>
<td>.1211</td>
</tr>
<tr>
<td>C</td>
<td>4.79 (±0.95)**</td>
<td>0.10 (±0.22)</td>
<td>0.00 (±0.01)</td>
<td>11.28 (±4.00)</td>
<td>-0.92 (±2.17)*</td>
<td>0.00 (±0.01)</td>
<td>-0.01 (±0.01)</td>
<td>.2252</td>
</tr>
<tr>
<td>D</td>
<td>-3.94 (±0.92)**</td>
<td>-0.07 (±0.22)</td>
<td>0.00 (±0.01)</td>
<td>13.96 (±4.54)**</td>
<td>4.97 (±0.95)**</td>
<td>4.87 (±1.06)**</td>
<td>4.37 (±1.09)</td>
<td>.1516</td>
</tr>
<tr>
<td>E</td>
<td>4.97 (±0.95)**</td>
<td>-0.05 (±0.21)</td>
<td>0.00 (±0.01)</td>
<td>5.99 (±0.68)**</td>
<td>4.37 (±1.06)**</td>
<td>4.87 (±1.06)**</td>
<td>4.87 (±1.06)**</td>
<td>.2371</td>
</tr>
<tr>
<td>F</td>
<td>4.37 (±1.09)</td>
<td>-0.05 (±0.22)</td>
<td>0.00 (±0.01)</td>
<td>5.99 (±0.68)**</td>
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<td>4.87 (±1.06)**</td>
<td>-0.03 (±0.21)</td>
<td>0.00 (±0.01)</td>
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<td>4.87 (±1.06)**</td>
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*p < .05; **p < .01.
living in Göteborg, Sweden. They suggest that, to predict IADL disability, a critical level in knee extensor strength might exist around 70 Nm and 120 Nm for 70-year-old women and men, respectively. In a recent study of older adults aged 60–96 years, Buchner et al. (20) identified a summary leg strength of 275 Nm as a possible strength threshold above which the slope equaled zero for the regression line between strength and gait speed. While a specific strength threshold would be useful in identifying those persons at increased risk of functional limitation, it is likely to be strongly influenced by the specific functional activity measured, particular muscles being tested, method of measurement, and characteristics of the sample being tested.

The design and size of the sample in our study did not allow for precise estimation of critical threshold levels. Future research needs to identify specific strength thresholds of key muscle groups for different functional tasks and to examine the extent to which these thresholds vary by age and gender subgroups. To accomplish such research, however, one must also identify the particular muscle groups that are primarily responsible for performing specific functional activity. Work by Wretenberg and Arborelius (34), for example, has identified that during a chair rise activity, hip and knee extensors were responsible for 99% of the total work performed, and that peak power output was greatest in the knee extensors, accounting for 72% of the total work. The identification of prime movers, such as chair rise activity, is key to identifying relevant strength thresholds for a specific functional activity and for the subsequent targeting...
of exercise interventions to improve functions that limit a person's functional independence. Such information is critical to the design of targeted strength training programs aimed at increasing functional performance in older persons.

Our analyses also uncovered a curvilinear relationship between balance and mobility in this community-dwelling, older sample. Identification of a 'balance threshold' similar to what has been described above for muscle strength needs to be pursued for intervention studies aimed at improving mobility in older persons.

The findings from this investigation also underscore Nagi’s and others’ thesis that the functional consequences of physiologic impairment are not the same as their disability consequences (3,6,7,35) and that each outcome variable in the disablement process needs to be analyzed in its own right (2). Understanding the effect of impairments (such as diminished skeletal muscle strength or balance) on functional limitations (such as mobility) does not tell us its effects on disability behavior (such as basic ADLs or IADLs).

Our finding that the magnitude of the association between strength and balance with disability was either eliminated or substantially attenuated in the presence of mobility restrictions in the model reinforces the importance of the intermediary role of functional limitations in the development of disability. Physiologic impairments such as diminished muscle strength and balance have a strong association with disability, primarily through their effect on functional limitations such as mobility limitations. These results clearly underscore the value of clinical trials that focus on prevention or treatment of functional limitations as a strategy for preventing disability (11). Human behavior involves the complex interaction of many physical, cognitive, and psychological factors and is far more than the sum of physiologic capacities. In this regard, it is important to understand that the variables included in these analyses explained less than half of the variance in total disability as measured by the total SIP. When we regressed total SIP on models that included age, gender, mobility performance, and both strength variables, we achieved an R² of .43. The results were similar for models included in these analyses explained less than half of the variance in total disability as measured by the total SIP.

In conclusion, these results supported the hypotheses of nonlinear relationships between muscle strength and balance both with mobility and disability in this sample of moderately disabled older men and women. Upper and lower extremity muscle strength and balance were curvilinearly related to mobility. Mobility, as hypothesized, predicted the presence of disability in this sample and showed a curvilinear relationship with severity of disability. Declining levels of muscle strength and balance were related to disability through their effect on mobility, supporting Nagi’s model of the disablement process (5,6). These findings further our understanding of the disablement of future interventions aimed at the prevention of functional limitation and disability.

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