Coimpairments: Strength and Balance as Predictors of Severe Walking Disability

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Background. Little information is available on the joint effects of multiple impairments (coimpairments) on the risk of disability. Our aim was to study the joint effects of strength and balance impairments on severe walking disability.

Methods. The data are from the baseline of the Women’s Health and Aging Study (WHAS), a study of moderately to severely disabled women. A total of 1,002 women aged 65 and older participated in the tests, which took place in their homes. Severe walking disability was defined as self-reported inability to walk one-quarter mile and customary walking speed in a 4-meter test of ≤0.4 m/s. Balance was measured as an ability to hold progressively more difficult stands (feet side-by-side, semi-tandem and tandem stands). Maximal knee extension strength was measured using a hand-held dynamometer.

Results. There were 129 women who were severely walking disabled but able to walk at least minimally. In logistic regression analysis, balance and knee extension strength were independent predictors of severe walking disability. To study the combined effects, nine groups were formed on the basis of strength tertiles by balance categories in the entire population. In the best balance category, the crude prevalences of severe walking disability were 1.2%, 4.9%, and 14.3% in the highest to lowest strength tertiles. In the middle balance category, the rates were 2.9%, 10.0%, and 45.4%, and in the poorest balance category 4.9%, 21.1%, and 42.6%, correspondingly. The age, body weight, and height-adjusted odds ratios (OR) showed that the risk of severe walking disability in the subgroup with best balance and strength was less than 5% of the risk in the subgroup with poorest balance and strength (OR .034, 95% confidence interval [CI] 0.07–.166). Correspondingly, in the subgroups with poorest strength and best balance (OR .097, 95% CI .025–.38) or poorest balance and best strength (OR .102, 95% CI .012–.866) the risk was about 10%. The age-specific estimates of prevalence of severe walking disability in women were: 2.0% for ages 65–74 years, 3.4% for ages 75–84 years, and 9.1% for ages 85 years and older.

Conclusions. The burden of coimpairments seems to be greater than the sum of single impairments involved. An effective way to reduce severe disabilities could be prevention of coimpairments.

MINIMUM levels of lower extremity strength and the ability to maintain postural stability in an upright position are prerequisites for walking ability (1–4). During walking, the center of the body mass is in continuous process of displacement and control. Postural stability during walking depends on the musculoskeletal elements holding the body upright and on the interaction of sensory information, central processing, and effector reactions. Balance has been found to be positively associated with measured and self-reported walking ability in older persons (5,6).

Many studies have found a positive association between lower extremity muscle strength and walking speed (7–9). The association may, however, be curved in shape and include thresholds (1,2,10). For example, a person needs to have at least a minimum level of strength to be able to walk at a given speed (11). When strength increases well above the minimum required level, a reserve capacity of strength evolves (2,10–12). The association of strength with walking speed is strongest below the reserve capacity threshold. At levels of strength higher than this threshold, an increase in strength no longer is related to an increase in functional performance (10).

As most studies have focused on independent effects of various impairments, little information is available on the joint effects of multiple impairments, termed here coimpairments, on the risk of disability. Studying coimpairments is particularly appropriate in older people, because with increasing age the proportion of those having impairments in multiple physiological systems increases (13). Duncan and coworkers (14) suggested that decline in physiological function may be better explained by the accumulation of deficits across multiple domains rather than by any single specific impairment. They found that among men aged 69 years and older (n = 39) those with poorest functional ability had the greatest number of impaired domains (sensory, musculoskeletal, or central processing). Tinetti and colleagues (15) found that when the number of impairments (lower and upper extremity, sensory, and affective impairments) increased from zero to one to two to three or more, the proportion of participants experiencing functional dependence doubled from 7% to 14% to 28% to 60%, respectively.

The aim of this cross-sectional study was to investigate the effect of balance and strength impairments on walking disability in older, moderately to severely disabled women; in particular, we sought to evaluate the combined effects of poor balance and strength deficits on walking disability.

METHODS

The data used in these analyses are from the baseline of the Women’s Health and Aging Study (WHAS), a prospective population-based study of causes and course of disability in older women. The sampling approach and study eligibility criteria have been described in detail previously (16).
**Sample**

Briefly, an age-stratified random sample of 6,521 community-dwelling women aged 65 years and older, with oversampling of those older than 85 years, was selected from the residents of the eastern half of Baltimore City and a part of Baltimore County, who were listed in the Health Care Financing Administration Medicare eligibility files. Of the 5,316 who were eligible, 4,137 participated in screening. Overall, 1,409 women met the criteria for study eligibility: (a) having difficulty in performing tasks in two or more of the following domains: mobility, upper extremity activities, basic self-care, and higher functioning tasks of daily living, and (b) scoring above 17 on the Mini-Mental State Examination (17). Of these, 1,002 women agreed to participate in the full study. They were extensively interviewed and were later visited in their homes by a trained nurse who tested their muscle strength, standing balance, and walking speed as part of the examination. The three nurses who did the examinations received extensive training for 5.5 weeks including practice, certification, and review before entering the field. Observation and debriefing continued in the field throughout the first month, and also periodically throughout the entire study.

**Procedure**

Of the 1,002 women, 901 did at least one knee extension strength test trial. The most common reason for not doing the test was high blood pressure (n = 55), and the second most common reason was that either tester or participant felt that doing the test was unsafe (n = 20). Seven women refused; five women could not do the test because of pain; three could not lift the foot; in six cases exclusion criteria were present (e.g., paralysis, cast, amputation); and in five cases other reasons prevented the test from being done.

In those who were able to lift the foot independently, maximal knee extension strength was measured using a hand-held dynamometer (Nicholas Manual Muscle Tester; Model BK-7454, Fred Sammons, Inc., Burr Ridge, IL). During testing the participant was strongly encouraged to exhibit the greatest possible force. The strength was measured as peak force and expressed as kilograms of force the examiner had to apply to break the isometric contraction. The best result of two trials was used in the analyses, unless only one was available. During knee extension strength testing, the participant was sitting on a hard chair with a hip angle of 90°. The knee angle was 105° (knee flexed 75° down from horizontal position). The dynamometer was placed proximal to the ankle joint. Interrater reliability of knee extension strength test was assessed in a pilot study including 22 women. The intraclass correlation coefficient was 0.91.

**Strength impairment** was defined as knee extension strength in the lowest tertile in the total study population. The cutpoints for tertiles were 10.6 kg and 15.1 kg.

**Static balance** was evaluated in three progressively more difficult stances: (a) feet side-by-side, touching; (b) semitandem, the side of the heel of one foot touching the big toe of the other foot; and (c) tandem, the heel of one foot directly in front of and touching the toes of the other foot. The tests were done without shoes. The participant was assisted to the starting position and was allowed to hold onto the tester’s arms to gain balance at the beginning of the test. If the participant held a stance for 10 seconds, she was asked to try the next more difficult position. Performance is scored from 0 to 4: 0 = unable to hold any stand, 1 = held side-by-side stand for 10 seconds; 2 = held side-by-side and semitandem stands for 10 seconds and tandem stand less than 3 seconds; 3 = held side-by-side and semitandem stands for 10 seconds and tandem stand for 3–9 seconds; 4 = held side-by-side, semitandem, and tandem stands for 10 seconds. In an earlier study, the stability of a similar scale has been found to be good, with Pearson correlation of 0.66 (18).

**Balance impairment** was defined as inability to hold side-by-side stand for 10 seconds.

**Walking speed** was measured by having the participant walk at her normal pace over a 4-meter course. In the homes of 85 women, only a 3-meter space was available, which was then used to test walking speed. The participant started from the standing position, and time was measured using a stop watch. Two trials were done and the faster one was used for these analyses.

Severe **walking disability** was conceptualized as inability to walk longer distances and having a lot of difficulty in walking even very short distances. For this study, severe walking disability was defined as usual walking speed in the 4-meter walk of 0.4 m/s or less and self-reported inability to walk a quarter of a mile (2–3 blocks), which was assessed using a five-category question: unable, a lot of difficulty, some difficulty, a little difficulty, no difficulty. The 0.4 m/s cutpoint was approximately the lowest quartile in the WHAS population. Moreover, in an earlier study (15), walking slower than 0.42 m/s was found to predict functional dependence.

Body mass was measured in kilograms using a digital scale with the participant wearing light indoor clothing. **Height** was measured to the nearest centimeter while the participant was standing in stocking feet with her head positioned against a doorway, using a Frankfort plane.

Ascertainment of 17 chronic conditions was accomplished utilizing standardized algorithms to validate the presence of disease based on data from interview and exam findings, x-rays, medications, physicians’ reports, and medical records (19). Only definite cases were used for the index.

**Statistical Methods**

Student’s *t* tests and chi-square tests were used to compare severely walking disabled women and women with mild to moderate walking disabilities. The odds ratios for severe walking disability were estimated from logistic regression models fitted to the data.

**RESULTS**

The screening for the WHAS captured nearly all women with severe walking disability in the overall population. The weighted screener data were used to estimate the prevalence of severe walking disability in women aged 65 years and older. Altogether, 10.4% of the screened population reported being unable to walk one-quarter mile: 8.8% qualified for the study as they reported disability in at least two domains (see Methods), 1.2% were cognitively impaired and did not qualify although they reported disability in at least two domains, and 0.4% reported disability only in one domain and thus did not qualify. We assume that among those reporting inability to walk one-quarter mile, walking speed does not differ between those who qualified but refused to participate (2.5%), those who agreed to participate (6.3%), and those who were disabled but were excluded due to cognitive impairment (1.2%). Walking speed of ≤0.4 m/s was measured in 56% of the exam participants who reported being unable to walk one-
Table 1. Characteristics of Subjects With Severe and Mild to Moderate Walking Disability

<table>
<thead>
<tr>
<th></th>
<th>Severe Walking Disability (n = 129)</th>
<th>Mild to Moderate Walking Disability (n = 814)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>Mean 83.6 SD 8.40</td>
<td>Mean 77.5 SD 7.72 &lt;.001</td>
</tr>
<tr>
<td>Number of chronic conditions</td>
<td>3.74 SD 1.93</td>
<td>Mean 2.87 SD 1.56 &lt;.001</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>62.3 SD 17.97</td>
<td>Mean 69.08 SD 17.16 &lt;.001</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>152.0 SD 7.44</td>
<td>Mean 155.6 SD 7.02 &lt;.001</td>
</tr>
<tr>
<td>Knee extension strength (kg)</td>
<td>10.13 SD 4.13</td>
<td>Mean 13.56 SD 4.90 &lt;.001</td>
</tr>
<tr>
<td>Balance Category</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>0. Unable to hold any stand</td>
<td>43.8</td>
<td>10.1</td>
</tr>
<tr>
<td>1. Held side-by-side stand for 10 seconds</td>
<td>33.6</td>
<td>21.7</td>
</tr>
<tr>
<td>2. Held side-by-side and semitandem stands for 10 seconds and tandem stand &lt;3 seconds</td>
<td>13.3</td>
<td>24.1</td>
</tr>
<tr>
<td>3. Held side-by-side and semitandem stands for 10 seconds and tandem stand for 3-9 seconds</td>
<td>8.6</td>
<td>18.1</td>
</tr>
<tr>
<td>4. Held side-by-side, semitandem, and tandem stands for 10 seconds</td>
<td>0.8</td>
<td>26.0 &lt;.001</td>
</tr>
</tbody>
</table>

*Based on Student’s t test.
†Based on chi-square test in 2 × 5 contingency table.

Table 2. Knee Extension Strength (kg) According to Balance Categories (N = 808)*

<table>
<thead>
<tr>
<th>Balance Categories</th>
<th>Mean SD</th>
<th>Mean SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. Unable to hold any stand</td>
<td>11.6 4.71</td>
<td>0.476 0.367-0.618</td>
</tr>
<tr>
<td>1. Held side-by-side stand for 10 seconds</td>
<td>11.4 4.67</td>
<td>0.910 0.856-0.968</td>
</tr>
<tr>
<td>2. Held side-by-side and semitandem stands for 10 seconds and tandem stand &lt;3 seconds</td>
<td>13.8 4.56</td>
<td>1.04 0.993-1.077</td>
</tr>
<tr>
<td>3. Held side-by-side and semitandem stands for 10 seconds and tandem stand for 3-9 seconds</td>
<td>13.9 4.56</td>
<td>0.476 0.367-0.618</td>
</tr>
<tr>
<td>4. Held side-by-side, semitandem, and tandem stands for 10 seconds</td>
<td>14.8 4.92</td>
<td>0.910 0.856-0.968</td>
</tr>
</tbody>
</table>

*Adjusted for age, height, and weight.

Table 3. Odds Ratios for Severe Walking Disability According to Balance and Strength*

<table>
<thead>
<tr>
<th></th>
<th>Odds Ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance category (1–5)</td>
<td>0.476</td>
<td>0.367-0.618</td>
</tr>
<tr>
<td>Knee extension strength (kg)</td>
<td>0.910</td>
<td>0.856-0.968</td>
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<tr>
<td>Age (year)</td>
<td>1.04</td>
<td>0.993-1.077</td>
</tr>
</tbody>
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*Adjusted for height and weight.

The women with severe walking disability were older, had lower body height and weight, poorer balance, and lower knee extension strength than the women with mild to moderate walking disability (Table 1). In the group with severe walking disability, only one woman was able to hold the tandem stand for 10 seconds; only 8% belonged to the highest strength tertile (cutpoint 15.1 kg); and 58.4% belonged to the lowest strength tertile (cutpoint 10.6 kg).

In the WHAS population (N=1,002) there were 160 women who were unable to walk one-quarter mile and had customary walking speed of ≤0.4 m/s. Of them, 31 women could not walk at all and were excluded from the analyses. In addition, 28 had missing data. Finally, there were 129 women who met the criteria of severe walking disability but were able to walk at least minimally. Altogether, 814 women did not meet the criteria for severe walking disability. Of these 814 women, 14.3% reported being unable to walk one-quarter mile, 22.4% reported a little, 17.2% some, 18.8% a little, and 29.4% no difficulty walking one-quarter mile. Sixteen women had customary walking speed ≥1.22 m/s and reported no difficulty walking one-quarter mile. Because only 10 women of the 814 were potentially not walking disabled, they were combined with the rest of the participants who can be characterized as having mild to moderate walking disability.

The women with severe walking disability were older, had lower body height and weight, poorer balance, and lower knee extension strength than the women with mild to moderate walking disability (Table 1). In the group with severe walking disability, only one woman was able to hold the tandem stand for 10 seconds; only 8% belonged to the highest strength tertile (cutpoint 15.1 kg); and 58.4% belonged to the lowest strength tertile (cutpoint 10.6 kg).

Balance and strength were positively associated (Table 2). Both poor strength and balance were significant predictors of severe walking disability (Table 3). A term assessing the Strength × Balance interaction was not significant and is not included in the model.

We examined the proportions of those with severe walking disability at different combinations of strength and balance levels. Strength was categorized into tertiles, and balance was recoded from five to three categories (original categories 1 and 2, as well as 3 and 4, were combined). Figure 1 shows that 42.6% of those with the combination of poorest balance and lowest tertile of walking speed ≥1.22 m/s and reported no difficulty walking one-quarter mile.
strength had severe walking disability, whereas in the group with the best balance and strength only 1.2% had severe walking disability. At middle and highest levels of strength the rate of severe walking disability rose substantially with decreasing balance. In the lowest strength tertile, very high rates of severe walking disability were observed for both lowest and middle balance groups. For each balance category, decreasing strength was associated with progressively higher rates of severe walking disability.

In the best balance category, the number of women in the best, middle, and poorest strength tertiles were 166, 104, and 81. In the middle and lowest balance categories these numbers were 103, 143, 150, and 21, 45, 54, respectively. Because only 2 women of the 166 in the best balance and strength group had severe walking disability, estimates using that group as the reference group for modeling purposes were too unstable. Consequently, we chose the group with poorest strength and balance as the reference group. Thus, the adjusted odds ratios for severe walking disability in the other eight groups formed on the basis of strength tertiles and balance categories are smaller than 1. In each balance category, the risk of severe walking disability decreased with increasing strength (Figure 2). The same was true for balance in each strength category. Among those in the poorest tertile of strength but the best balance category (able to hold semitandem or tandem stand for 10 seconds), and those with poorest balance but best strength (highest tertile, ≥15.1 kg), the risk of being severely walking disabled was about 10% of the risk of those having both impairments. In the group with the best knee extension strength and the best balance, the risk of being severely walking disabled was about 3% of the risk of the group with impaired strength and balance (OR .034, 95% CI .0073-.166).

**Discussion**

The impairments studied here — namely strength and balance — are the immediate and most important prerequisites for the ability to walk. We found cross-sectionally that the risk of being severely walking disabled was 10 times higher for those having both strength and balance impairment when compared to those with only one impairment.

In the model of the disablistment process (21,22), the causal pathway is seen to go from pathologies to impairments to functional limitations and disabilities. In these data, balance and lower extremity muscle strength were related to each other and could be independent impairments or causally related to each other. Several scenarios of the process are plausible. For example, poor balance results in decreased participation in household and recreational activities because of fear of falling. Reduced activity then causes further impairments, such as decreased muscle strength. On the other hand, muscle strength that has decreased close to the minimum required for given tasks will cause tiredness or reduced speed in people performing these activities (9). In older women, everyday tasks, such as standing up or climbing stairs, may become almost maximal performances due to declined strength. Difficulties in walking or stair climbing will predispose people to cut the frequency of doing these tasks to the minimum. Spending most of the days sitting or resting results in balance problems, which will then increase the risk of further disability. It is also possible that poor strength directly causes balance problems during walking. About two thirds of the human body mass is centered in the upper body, and consequently the upper body can store a lot of potential energy. During walking, the center of mass is in continuous process of displacement and control, and postural stability depends among other things on the musculoskeletal elements holding the body upright (23).

Our results are in accordance with previous studies showing that the number of impairments was associated with an increasing rate of negative outcomes such as functional dependency, falls, and incontinence (15). Duncan and colleagues (14) found that the number of impairments was inversely associated with balance. However, we are not aware of any previous studies that assess coimpairments as risk factors for walking disability. The 10 times higher risk of severe walking disability among those with both balance and strength impairment emphasizes that presence of coimpairments, rather than single impairments, may put older people at very high risk of severe disability.

It seems to be possible to compensate for one impairment with an assistive device and extra capacity in other physiological domains. For example, in the current study there were 82 women who needed to use a walker to do the 4-meter walk; 50 of these women were unable to stand independently, so they had the poorest balance score. Seven of the women using a walker and unable to stand had knee extension in the highest tertile. Their customary walking speed was significantly higher ($M = .45 \text{ m/s}, SD .14, p = .048$) than in the middle ($M = .36 \text{ m/s}, SD .13, n = 12$) or low-
est strength tertile ($M = 34 \text{ m/s}, SD = 14, n = 22$). This demonstrated that even in the presence of very serious balance impairment, muscle strength was positively associated with walking ability. However, the observed difference in walking speed, although statistically significant, was in absolute terms small.

Causality can best be determined in experimental studies aiming to rehabilitate the impairments in question. Both strength and balance are potentially modifiable. In healthy older women, progressive strength training programs with a duration of 12 to 18 weeks have been found to result in 19%–27% increases in isometric knee extension strength (24,25). Also, in frail nursing home residents increases of up to 100% to 200% in one repetition maximum have been reported following 8–12 weeks of progressive resistance training (26). This shows that potential strength improvements in frail older people are similar to those in healthier old people, as an increase of 100% in one repetition maximum corresponds to an approximately 10% increase in isometric or isokinetic strength (27). Improvements in postural control have also been found following exercise intervention. Judge and colleagues (28) reported decrease of sway in single stand in 62- to 75-year-old women following a 6-month strength, endurance, and balance training program. However, studies showing long-term functional benefits resulting from increased strength or improved balance still remain to be done.

Prevention of walking disability is important from the point of view of an individual's quality of life as well as the health care system, as poor mobility has been shown to predict further disabilities and nursing home admissions (29,30). A considerable decrease in severe walking disability might be achieved by prevention programs aiming at decreasing the presence of coimpairments, or by reducing risk factors leading to multiple impairments. This research suggests, however, that improvement in only one impairment can have a substantial impact on the probability of severe walking disability.

ACKNOWLEDGMENTS

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