Functionally Relevant Thresholds of Quadriceps Femoris Strength

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The purpose of this study was to identify quadriceps femoris strength thresholds below which performance on ambulatory tasks is compromised. A second purpose was to evaluate whether self-reported functioning matches evaluated performance of the activities. Subjects (N = 100; age 73 ± 0.9 years) participated in isometric knee extension strength tests, performed three functional ambulatory tasks (chair rise, gait speed, and stair ascent and descent), and answered standard survey questions assessing physical function. Significant relationships were observed between functional performance and the ratio of isometric leg extension peak torque to body weight (STR/WT) for each activity (p < .0001). For each activity, thresholds of STR/WT between 3.0 and 3.5 N m/kg were observed, below which the likelihood for success was reduced. Thresholds were determined by calculating the value of STR/WT that minimized the classification error. Individuals with a STR/WT < 3.0 N m/kg are at a substantial risk for impaired function in chair rise, gait speed, and stair ascent and descent. Sensitivity and specificity of STR/WT as a predictor of functional success ranged from 76% to 81% and from 78% to 94%, respectively, depending on activity. This is of clinical significance, as the STR/WT thresholds can identify individuals with preclinical disability (beginning to have difficulty with ambulatory tasks) as opposed to those in whom an outright disability is observed. This may be useful for targeting individuals for strengthening interventions and developing specific intervention goals.

It is well known that muscle strength typically declines with age, even in healthy individuals (1,2). It is also widely accepted that lower limb muscle strength is related to the ability to perform ambulatory activities such as rising from a chair, walking at an appropriate speed, and ascending and descending stairs (3). The decline in muscle strength has important functional consequences that contribute to a public health burden—approximately 10% of apparently healthy community-dwelling adults over the age of 75 years lose independence in basic activities of daily living (ADLs) each year (4). The decline in lower body muscle strength may be associated with gait disorders, falls, hip fractures, and loss of independence caused by poor ambulation (5). For example, gait velocity decreases at a rate of 12–16% per decade after age 60 (6).

In addition to strength, other factors influence the ability to perform functional tasks, including flexibility or range of motion, choice of strategy, vision, balance and postural control, muscular endurance, pathology, and cognitive ability. Although many factors are involved, several studies have suggested muscular strength to be one of the most important factors limiting the ability to perform many functional tests including ADLs and instrumental activities of daily living (IADLs) in the elderly population (5,7,8). The ability to stand from a seated position is one of the most important measures of physical function, is essential for independent living, and is one of the most biomechanically demanding functional tasks (9). In 1987, approximately two million people over the age of 64 years had difficulty rising from a chair (10). Knee extensor (quadriceps femoris) strength has been identified as the most important factor limiting the ability to rise from a chair (8) and is crucial to a variety of other ADLs (11–14).

Because lower limb muscle strength is so critical to independent living and is relatively easy to improve compared with most pathologies, substantial efforts have been made toward encouraging the elderly population to participate in resistance training programs. This is reflected in both the research literature and community-based programs. Many professional organizations now recommend resistance exercise training for men and women of all ages, including the elderly population (15,16). However, these recommendations are vague and suggest general strengthening exercises for the entire healthy population. Little or no research has evaluated the specific exercise training needs of older individuals as related to everyday function. If functionally relevant thresholds of strength could be identified, they could be useful for targeting individuals for early interventions to help prevent outright disability, and they could be used as specific goals for strength training programs for the elderly population. Such thresholds, if they exist, could help answer important questions such as Which individuals should be specifically targeted for strengthening programs? and How strong do they need to be to perform ambulatory skills inde-
pendently? If we can identify individuals who are beginning to have trouble (pre-clinical disability) and target them with strengthening interventions, then we might be able to influence public health by keeping more older people independent longer.

Discrepancies between objective measurements (strength, rated performance, etc.) and self-report of functioning are particularly important in light of recent public policy issues. ADL limitations are an important factor in determining eligibility for federally funded nursing and home-care services, as well as for reimbursement of privately insured long-term care services. In such situations, professional assessments are used. However, policy and program planning and forecasts of program costs depend on self-reported prevalence data collected in surveys. Declines in self-reported disability prevalence since the early 1980s have been interpreted as evidence of improving population health (17,18) and have been used to argue that future demands for services may not grow despite the large projected increases in the numbers of elderly individuals (19,20).

Therefore, one purpose of this study was to define functional thresholds of quadriceps femoris muscle strength below which function on ambulatory tasks is reduced. A second purpose was to evaluate how self-report of physical function is related to muscle strength and observed performance of the same task, because many important decisions are currently made based upon self-reports. The specific hypotheses tested were that, first, a threshold of quadriceps femoris peak isometric torque corrected for body weight could provide a functionally relevant indicator of function for chair rise, maximal gait speed, and stair ascent and descent; and, second, that self-report would match observed performance of chair rise.

METHODS

Subjects

One hundred community-dwelling men and women aged 52–92 years volunteered for participation. Most subjects were recruited through local senior centers or clubs, but some were recruited through adult day care and assisted living facilities. We sought to recruit a wide variety of individuals of varying age, muscle strength, and functional ability; Tables 1–3 describe the subject population in detail. Subjects were excluded if they had health problems that contraindicate strength and functional testing, such as severe orthopedic limitation, uncontrolled cardiovascular disease, or severe cognitive impairment. Subjects gave informed written consent; the study was approved by the Syracuse University Institutional Review Board.

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unbalanced during or after rising, paused in midrise, or used an alternative strategy such as scooting to the front of the chair before rising; and “difficulty” indicated the subject could only rise with hand support (either using their hands to push on their thighs or pushing on the chair itself) or was completely unable to rise unassisted. Reliability (Pearson $R$) for this rating scale was $r = .95$ (intertrial) and $r = .93$ (interinvestigator) in our laboratory ($n = 39$; mean age $65 \pm 16$ years). In the current study, a single investigator rated all subjects; thus reliability was probably even higher. Because pilot data collection showed a correlation of $.95$ between repeat trials of the same subject, only one trial was used for the study.

Gait speed.—Subjects were timed while walking 25 ft ($\sim 7.61$ m) at their fastest pace (not running). Subjects were rated as “no difficulty” or “difficulty” while walking at 1.22 m/s, which is the speed required to cross a signaled intersection (21). “No difficulty” indicated the subject could walk at a speed of 1.22 m/sec or faster; “difficulty” indicated they were unable to walk at that speed.

Stair ascent and descent.—Subjects were asked to walk up and down 12 steps as fast as comfortably possible without using the handrailing for weight support. Subjects were timed for going up the stairs, the amount of time spent resting, and the time going down the stairs, and they were rated based on their use of the handrail (balance vs weight support), ability to ascend and descend all 12 steps, and choice of strategy. The following rating categories were used: “No difficulty” indicated that a subject was able to climb all 12 stairs without relying on the handrail for weight support, and walked one leg after the other; “difficulty” indicated use of the handrail for weight support, use of hand on his or her legs for weight support, the inability to climb all 12 stairs, or the use of alternative strategies. Reliability (Pearson $R$) was $r = 1.0$ and $.93$ (intertrial) and $r = .74$ and $.78$ (interinvestigator) for stair ascent and descent, respectively ($n = 13$; mean age $82 \pm 7$ years). In the current study only one investigator rated all subjects, so reliability would be expected to be higher than in the pilot. Again, because of the high correlation between trials, only one trial was used for this study.

Identification of risk thresholds.—Thresholds of STR/WT below which functional performance of each of the tasks was impaired were calculated. The risk threshold was identified as the value that optimally discriminates between the “difficulty” and “no difficulty” classes. The thresholds minimize the sum of type I errors (incorrectly categorizing those who actually have difficulty) and type II errors (incorrectly categorizing those who actually have no difficulty). These thresholds maximize the sum of specificity and sensitivity.

Self-report of ADL and IADL.—Subjects answered physical activity questions from the Longitudinal Study of Aging, including section Q, conditions and impairments, and sections R1 and R2, ADL and IADL performance (22). The survey directions specified that subjects self-report difficulties with various ADL and IADL tasks “by themselves and without special equipment.” The survey questions were administered before the functional and strength testing (Tables 2 and 3). Data analyses focused primarily on the chair rise question because it was most closely related to a measured performance task. The wording of the chair rise questions were, first, “Because of a health or physical problem do you have ANY difficulty getting in and out of bed or chairs? [ANSWER Yes or No]” and, second, “[If yes]: By yourself and without using special equipment, how much difficulty do you have getting in and out of bed or chairs? [ANSWER Some, A Lot, or Unable].”

**Statistical Analyses**

All statistical tests were performed by using SPSS software (SPSS, Chicago, IL). A $p$ value of .05 was used to reject the null hypotheses.
Physiological Measures

Multiple regression analyses were used to determine the collective and independent contributions of STR/WT and age in predicting functional performance. Risk thresholds for STR/WT were determined for each functional task by identifying the STR/WT that optimally discriminates between those with difficulty and those with no difficulty.

Survey Self-Reports

Of the functional tasks studied, the chair rise performance test was most closely matched with a specific survey question. Therefore, chair rise was selected for analysis of agreement between self-reports and actual behavior. Frequency counts were calculated for the rating of both observed and self-reported chair rise performance. Cohen’s kappa statistic was used to determine whether there was greater than chance agreement between self-reported and observed performance. McNamar’s test of symmetry was used to analyze whether discrepancies between self-reported and observed performance were overstated or understated by subjects.

Results

STR/WT as a Predictor of Function

Of all the joint angles tested, STR/WT at 60° was the most highly correlated with the functional tasks ($R = .38–.50; p < .001$) and so STR/WT at 60° was chosen for subsequent data analysis.

Table 4 shows multiple regression analyses that demonstrate two important points. First, STR/WT is a much better predictor of functional ability than age, regardless of what is used as the dependent variable. The $sr^2$ column represents the squared semipartial correlation, which is an indicator of the independent contribution of each variable. The $sr^2$ indicates the amount that the total $R^2$ would be reduced if the variable were omitted from the model. The combination of STR/WT and age does yield a better prediction than either variable alone, however. The second important point is that when the categorical rating of function is used as the dependent variable, a better regression equation is achieved (higher $R^2$) than when time to completion is used as the dependent variable. Therefore, subsequent analyses and graphs use the categorical rating as the dependent variable.

Identification of Functional Thresholds of Muscle Strength

Thresholds for STR/WT were identified below which function on the various tasks was likely to be impaired. The risk thresholds and distribution of individual data are shown in Figures 1–4 for each of the functional tasks. Generally, the STR/WT threshold was around 3.0 (range 3.0–3.5, depending on activity). Table 5 shows the sensitivity and specificity for each threshold. A true positive is defined as STR/WT < threshold and observed task difficulty; a false positive is STR/WT < threshold with no observed task difficulty; true negative is STR/WT > threshold with no observed task difficulty; and a false negative is STR/WT > threshold with observed task difficulty.

Table 6 shows the mean STR/WT and time required to complete the task for the subjects based on their functional abilities. The percentage of subjects who exhibited difficulty varied by performance task. For example, 56% of subjects were observed to have no difficulty, 29% some difficulty, and 15% a lot of difficulty on the chair rise. Seventy percent of subjects had no difficulty walking at 1.22 m/s, 63% had no difficulty with stair ascent, and 65% had no difficulty with stair descent.

Self-Report of Function

Frequency counts for the chair rise observed versus self-reported performance are shown in Table 7. Cohen’s kappa $Z$ statistic yielded a $p$ value of .000, indicating that there was agreement between self-report and actual behavior that was greater than chance. The self-report matched the observed performance 77% of the time. McNamar’s test of symmetry yielded a $p$ value of .0043, indicating asymmetry. Where there were discrepancies between self-report and observed performance, significantly more subjects (82%) overstated their capabilities than underated them (18%). There were no significant gender or age effects for either test.
DISCUSSION

The results indicate a clear relationship between muscle strength and performance ratings. Thresholds of STR/WT were observed below which leg strength began to impair function (Figures 1–4). As expected, stronger individuals were more likely to successfully complete the tasks. Our results show that a STR/WT ratio of approximately 3.0 is necessary to walk at an appropriate speed and ascend and descend stairs. A slightly higher ratio (~3.5) is required for successful performance of chair rise. The sensitivity and

Figure 1. Observed threshold (---) of leg extension peak isometric torque to body weight ratio (STR/WT) by age for subjects observed to have no difficulty, some difficulty, and a lot of difficulty on the chair rise activity. Individual data are shown (n = 99).

Figure 2. Observed threshold (---) of leg extension peak isometric torque to body weight ratio (STR/WT) by age for subjects measured to be able or unable to walk at 1.22 m/s. Individual data are shown (n = 99).
specificity values shown in Table 5 give an indication of how well the thresholds describe the functional performance. For example, for chair rise a STR/WT ratio of 3.5 correctly identifies 81% of those who had some difficulty and all but one of those who had a lot of difficulty in this data set (sensitivity). The specificity value of 78% indicates that the proposed threshold correctly identifies 78% of those subjects with no difficulty rising from a chair. The sensitivity values for all tasks were similar, ranging from 76% to 81%. The specificity values were more variable with the gait speed...
and stair ascent and descent thresholds, yielding 87–94% compared with only 78% for chair rise.

The large statistical difference in STR/WT and time to completion of each task among the performance groups indicates that weaker individuals (relative to body weight) had more difficulty with the tasks (Table 6). This lends support to the use of our rating criteria for evaluating the tasks. Furthermore, the criteria were better able to discriminate between those who did and did not have difficulties compared with measuring time to completion of the task (Table 4). This may be somewhat surprising, because it is often assumed that continuous variables such as time to completion provide better information than categorical ratings. This was not the case in this study; the categorical rating proved to be a better discriminator, suggesting that how long it takes to perform a specific task is not particularly important in and of itself.

Little research has attempted to identify strength thresholds below which everyday function is impaired. Possible thresholds of quadriceps femoris strength required for adequate walking speed have been evaluated in two studies. The first identified a walking speed of 1.22 m/s as functionally relevant (speed required to cross a signaled intersection) and evaluated leg strength by using handheld dynamometry in a fairly unusual population—disabled women over age 65 years (23). It was concluded that 2.3 N m/kg of quadriceps femoris strength was a cutoff point above which walking speed did not increase in disabled women. A second study suggested that a critical knee extensor strength may exist of 70 N m for women and 120 N m for men at age 70 years, below which individuals would fail to walk at 1.5 m/s (women) and 1.7 m/s (men). The functional relevance of these walking speeds was not stated, but considering the differences between the two populations under study (disabled vs independent subjects), the values seem reasonably comparable. Both of these studies are similar to our finding of a threshold of around 3 N m/kg for STR/WT. Several other studies have taken an entirely different approach and used regression analyses to predict the influence of lower limb strength on ambulatory function. Instead of defining a specific threshold, these studies have emphasized that a nonlinear model produces higher $R^2$ values than a linear model (23–26). This supports the idea of a functional threshold, below which function is impaired, and above which function is not appreciably improved.

Our results show, to our knowledge for the first time, that this approximate threshold is appropriate for walking and stair ascent and descent, and that chair rise requires slightly greater STR/WT. Indeed, for optimal functioning (mean of the No Difficulty group), the thresholds of STR/WT are closer to 4.2–4.5 (see Table 6 and Figures 1–4).

One important aspect of the current study is that the STR/WT thresholds are useful for identifying those individuals who exhibit preclinical disability, meaning that they are beginning to have difficulty with the tasks but do not yet show an inability to perform or an outright disability. Such thresholds should prove useful for identifying individuals who should be targeted for strengthening intervention and would provide goals for such intervention.

The survey analysis compared self-reported chair rise ability to observed behavior and found agreement approximately 77% of the time. When discrepancies occurred, significantly more subjects (82%) overstated their capabilities than understated them (18%). Neither age nor gender is related to agreement between self-report and actual behavior. Self-reported difficulties with physical and personal care activities have been used to determine prevalence and trends in disability at older ages, used as major criteria for establishing new social policies, for estimating the size of the eligible population for proposed assistance programs, and as predictors of various outcomes including nursing home admission, use of health care resources, and mortality (27–29). Despite all this, there is little research documenting whether actual performance matches self-reported activity, and in fact substantial measurement error has been associated with self-reports of physical function.

### Table 5. Associated Sensitivity and Specificity of the STR/WT Threshold

<table>
<thead>
<tr>
<th>Parameter</th>
<th>STR/WT</th>
<th>Specificity</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chair rise</td>
<td>3.54</td>
<td>78</td>
<td>81</td>
</tr>
<tr>
<td>Gait speed</td>
<td>3.00</td>
<td>87</td>
<td>76</td>
</tr>
<tr>
<td>Stair ascent</td>
<td>3.04</td>
<td>90</td>
<td>78</td>
</tr>
<tr>
<td>Stair descent</td>
<td>3.04</td>
<td>94</td>
<td>81</td>
</tr>
</tbody>
</table>

*Notes: Percentages indicate ability to categorize individuals accurately for each activity. STR/WT = leg extension strength to body weight ratio.*

### Table 6. Mean STR/WT ± SE and Time to Completion

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No Difficulty</th>
<th>Some Difficulty</th>
<th>A Lot of Difficulty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chair rise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STR/WT</td>
<td>4.48 ± 0.18</td>
<td>3.13 ± 0.17</td>
<td>2.38 ± 0.26</td>
</tr>
<tr>
<td>Time (s)</td>
<td>1.64 ± 0.05</td>
<td>2.51 ± 0.15</td>
<td>5.86 ± 0.69</td>
</tr>
<tr>
<td>Gait speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STR/WT</td>
<td>4.24 ± 0.51</td>
<td>—</td>
<td>2.61 ± 0.19</td>
</tr>
<tr>
<td>Time (s)</td>
<td>6.42 ± 0.22</td>
<td>—</td>
<td>16.60 ± 1.66</td>
</tr>
<tr>
<td>Stair ascent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STR/WT</td>
<td>4.38 ± 0.17</td>
<td>—</td>
<td>2.75 ± 0.15</td>
</tr>
<tr>
<td>Time (s)</td>
<td>7.08 ± 0.14</td>
<td>—</td>
<td>14.43 ± 1.21</td>
</tr>
<tr>
<td>Stair descent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STR/WT</td>
<td>4.40 ± 0.16</td>
<td>—</td>
<td>2.63 ± 0.15</td>
</tr>
<tr>
<td>Time (s)</td>
<td>6.47 ± 0.22</td>
<td>—</td>
<td>16.60 ± 1.66</td>
</tr>
</tbody>
</table>

*Notes: STR/WT = leg extension strength to body weight ratio; SE = standard error. Subjects rated with no difficulty, some difficulty, or a lot of difficulty for chair rise and rated as no difficulty or a lot of difficulty for gait speed and stair ascent–descent. There were significant differences among all groups within each task for STR/WT and time at $p < .05$.***

### Table 7. Frequency Counts for Observed Chair Rise vs Self-Reported Performances

<table>
<thead>
<tr>
<th>Self-Reported Performance</th>
<th>Observed Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Difficulty</td>
<td>51</td>
</tr>
<tr>
<td>Difficulty</td>
<td>18</td>
</tr>
<tr>
<td>Difficulty</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>26</td>
</tr>
</tbody>
</table>

*Note: Each count represents the number of subjects in each category.*
(28,29) Reliability coefficients for several survey-based measures of disability have been reported that are lower than our observer rating measures (30).

There were some limitations to this study. One is a classic argument in the measurement of disability—should you provide objective instructions to measure a person’s ability in a standardized manner, or alternatively provide no instructions and observe the person’s usual manner (often termed performance)? For this study we provided objective instructions to the subjects such as “rise from the chair as quickly as possible” in an effort to measure ability. This was an effective strategy as evidenced by the identification of functionally relevant thresholds of STR/WT, but we cannot predict how the results would differ if subjects received alternative instructions for task performance. A second limitation is that subjects self-reported their medical histories and this was not independently verified by a clinical examination. This should not pose significant problems as the testing procedures themselves were low risk, subjects with significant cognitive impairments were not included, and minor inaccuracies in the self-reported medical history are unlikely to influence the study conclusions. It is also interesting to note from Tables 1–3 that the subjects under study represented a wide range of age, muscle strength, and functional capacity, and about a third did self-report difficulty in at least one ADL or IADL.

In summary, the major finding of this study was the identification of functional thresholds of quadriceps femoris strength, below which chair rise, gait speed, and stair ascent and descent functions began to be impaired. Although it is clear that many factors in addition to muscle strength affect ambulatory ability, these thresholds may be used to identify individuals at risk for loss of ambulatory independence as a result of inadequate quadriceps femoris strength. Such thresholds may be useful in targeting individuals for intervention programs before they become dependent, as opposed to waiting until outright disability is observed. A secondary finding was that survey self-report of chair rise ability matched observed performance approximately 77% of the time. When discrepancies did occur, there was a bias toward overestimation of ability. This suggests that many older individuals may not be aware of their diminished leg strength and the possibility of gradual loss of independence, and thus might not present themselves for early interventions. Alternatively, if people perceive their level of functioning to be better than indicated by objective strength tests, and they seek or receive intervention services based on their perceived levels, then measures of the effectiveness of those interventions will be biased downward. This further supports the use of objective leg strength measures for early identification of those at risk for loss of functional independence.

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