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Exploring the Hierarchy of Mobility Performance in High-Functioning Older Women

Carlos O. Weiss^{1,2}, Linda P. Fried^{1,2}, and Karen Bandeen-Roche^{1,3}

¹Center on Aging and Health, Johns Hopkins Medical Institutions, Baltimore, Maryland. ²Division of Geriatric Medicine and Gerontology, Johns Hopkins Medical Institutions, Baltimore, Maryland.

³Department of Biostatistics, Johns Hopkins Medical Institutions, Baltimore, Maryland.

Abstract

Background—Preventing mobility disability depends on matching interventions to individual needs. The purpose of this study is to improve targeting by determining whether mobility performance is associated with, and predicts, mobility disability hierarchically. The hypothesis is that poorer performance tested by more demanding tasks is more strongly associated with current and future mobility “limitation” (self-reported task modification or difficulty) than is that tested by less demanding tasks, in a graded manner.

Methods—Data come from the Women’s Health and Aging Study II ($n = 436$) at baseline and at 36-month follow-up. Logistic and multinomial regression models examined associations between performance on mobility tests and reported limitation in walking one-half mile, adjusting for risk factors for disability.

Results—We found that 76.6% of prevalent and 88.4% of new-onset self-reported limitation fit within the hypothesized hierarchical pattern. The estimated strength of association between a decrement in lower extremity performance and reported limitation increased with task demand for the primary outcome, reported limitation in walking one-half mile. For example, the odds ratios for prevalent report of walking limitation, versus no limitation, for 10% lower performance walking, dressing, repeating chair stands, and climbing, respectively, were 1.05 (95% confidence interval, 0.97–1.17), 1.08 (1.00–1.16), 1.15 (1.06–1.25), and 1.22 (1.12–1.33).

Conclusions—This study partially supports the hypothesis that mobility performance tends to follow a hierarchical pattern. For studying mild mobility disability, walking speed may not be as useful as more demanding tests. Identifying declines in performance through more demanding tests such as climbing should improve the ability to target preventive interventions to individuals at risk of mild mobility decline within a high-functioning population.

Mobility disability is common and predicts serious adverse outcomes. Thirty-one percent of individuals age 65 or older in the United States have difficulty climbing a flight of stairs (1). Reported mobility disability is associated with an increased risk of disability in basic Activities of Daily Living (ADLs) (2), institutionalization, and death (3–5). Approximately half of mobility disability develops gradually, rather than abruptly, suggesting the potential to identify

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Address correspondence to Carlos Weiss, MD, MHS, Center on Aging and Health, Johns Hopkins Bloomberg School of Public Health, Suite 2-700, 2024 E. Monument Street, Baltimore MD, 21205. cweiss9@jhmi.edu.

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individuals early in mobility decline (6–8). To prevent or reverse mobility disability, effective targeting of interventions is essential.

Prior population-based research suggests that targeting preventive interventions to individuals who do not yet have advanced disability could lead to a higher impact than acting on recovery. The evidence for this comes from studies observing that, whereas rates of progression into a disabled state are differential by risk strata, rates of recovery are equal. As examples, young-old or more educated individuals are less likely to become disabled than are old-old or less educated individuals, but likelihood of recovery does not differ across these groups (9,10). Thus, it may be that the mechanisms of recovery differ from mechanisms of prevention. Assuming equally appropriate efforts, it is unlikely that intervening to enhance recovery would more efficiently optimize mobility functioning over the course of older age than would well-targeted prevention. Lower extremity performance has been shown to be predictive of mobility disability, making it a potential means for improving targeting (8,11–14). It has been hypothesized that there is a hierarchical pattern to changes in lower extremity function in real-world tasks, but this hypothesis has only been examined through an observer scoring method (15).

The purpose of this study was to determine whether objective performance hierarchically predicts early mobility disability. The hypothesis was that mobility disability begins in a patterned way, reflecting ordered differences in demand among mobility tests. The first research question was whether a proposed hierarchy is supported by the patterns of prevalent and new self-reported mobility limitation (defined in the Methods section). Second, the study examined whether slower performance is differentially associated with self-reported limitation in an ordered way, such that decreased performance in more demanding tests is more strongly associated with reported decrements in physical function than are decreases in less demanding tests. Finally, the study assessed whether the hierarchy of performance was consistent with an extension of Fitts' theory of motor control (16), which posits that as movement demand increases, speed with which it is performed decreases. The extension of the theorem holds that, at higher demand, less capable individuals are differentially slowed (17,18). It was expected that individuals who walked slowly would be slowed relatively more by more demanding tests.

METHODS

Data

The data used come from the Women's Health and Aging Study II (WHAS II), a longitudinal cohort designed to ascertain the causes and course of disability. Eligibility was defined on the basis of self-reported task difficulty (in ≤ 1 of 4 physical domains), Mini-Mental State Examination (19) score ≥ 24 , and ability to participate in a clinic examination. Four hundred thirty-six participants were recruited from among the higher functioning two thirds of community-dwelling women age 70–79 years in eastern Baltimore City and County, Maryland (20). Enrollment took place in 1994 and 1995, with examinations every 18 months. Data from 36-month follow-up were chosen for the longitudinal portion of this study to allow an adequate length of time for the development of outcomes in this initially high-functioning group.

Outcome Measures

The following gradient of demand was hypothesized on the basis of combining prior knowledge (21–27) with biologic plausibility: walking a long distance is more difficult than climbing 10 steps, which is more difficult than transferring from a bed or chair, which is more difficult than dressing, which is more difficult than walking a short distance on a flat surface. Two questions were posed for each task: "Have you had difficulty..." and "Have you changed the way you (task) or how often you do this, due to a health or physical condition?" Mobility limitation was

operationalized as an affirmative response to either question. The rationale for this combination is based on the goal of including individuals in an early phase of mobility decline. Prior work showed that self-reported modification identifies individuals at risk for task difficulty, and thus is on the same disability pathway (20). Exploratory data analysis for this work confirmed that responses to these questions showed similar relationships to performance.

Two primary outcomes were evaluated: (i) self-reported limitation walking one-half mile, and (ii) self-reported limitation in any 2 or more nonwalking mobility tasks (dressing, transferring, or climbing). The first outcome is more difficult and develops early. The second outcome was chosen (i) to extend confidence in the findings, (ii) because it does not rely on responses to a single item, and (iii) because an accumulation of early changes is likely to be more relevant to loss of independence. Because reported prevalence at any point in time consists of a mixture of short-term (transient) and long-term disability (28,29), we performed a sensitivity analysis studying self-reported limitation that was not present at baseline, appeared at 18 months' follow-up, and persisted until the second follow-up.

Main Independent Variables

Performance was measured using standardized tests of timed performance (to 0.1 seconds) chosen because of their reliance on lower extremity function and similarity to real-world activities: walking at usual speed for 4 meters from a standing start; repeating 5 chair stands as quickly as possible (straight back chair approximately 19 inches high, arms folded); dressing by putting on oversized scrub pants (sitting allowed); and climbing 10 steps (rail use allowed). To examine the association between self-reported limitation and performance, performance speeds were converted into ranked percentiles. This conversion was done to make comparisons across tests that inherently require measurement on different metrics (e.g., meters per second vs stairs per second). Speeds were scaled and inverted so that odds ratios (ORs) indicate the multiplicative increase in odds of self-reported limitation, versus no limitation, for a performance decrement of 10%.

Analytic Methods

The prevalence and development of new-onset cases of self-reported limitation across mobility tasks were calculated, and patterns across tasks were tabulated. Baseline prevalence ORs were calculated using logistic regression models. For future self-reported limitation, multinomial regression models examined conditional ORs (CORs) while allowing for a competing outcome, namely death, by using a categorical variable. Individuals with self-reported limitation at baseline were excluded from predictive analyses. Potential nonlinearity in relationships was assessed with locally weighted scatter plot smoothers to view the "function" relating continuous performance on different tests to the log odds of an outcome. Additionally, the association with the outcome was allowed to vary for each quintile of performance by introducing linear spline terms, thus allowing break points (30). Due to missing information on variables of main interest, 30 individuals were not used for baseline analyses, leaving 406. For logistic regression models, covariates considered due to a priori knowledge included race (African American, white), age (75+ vs 70–74 years), education (years), living alone (binary), poverty (having not enough or just enough to make ends meet at the end of each month, binary), Geriatric Depression Scale (GDS) (31) score (continuous), body mass index (kilogram/meter², continuous), and comorbidity (count from among 14 diseases). Likelihood ratio tests comparing nested and extended models assessed the contribution of covariates (singly and in combination) and interaction terms, with the goal of identifying the most parsimonious model. Collinearity was assessed by examining variance inflation factors. Hosmer–Lemeshow chi-square goodness-of-fit statistics tested the fit of final models with data. Cross-validation checking models against "external" data was performed by selecting $n-1$ random individuals to be removed, then predicting each removed individual one at a time from a model fit from

the remaining data, before calculating goodness-of-fit (32). Missing information was low in this study (<5% for any one variable), thus complete case analysis was performed. To test whether systematic differences in missing data might change findings, sensitivity analyses were performed using multiple hot-deck imputation and imposing standard deviation units of -1, -0.5, 0, +0.5, and +1 on imputed values (33). Stata 8.2 (34) was used for analyses.

Consistency with the extension of Fitts' theorem was assessed using locally weighted scatter plot smoothers to examine how speed on more demanding tests (dressing, chair stands, and climbing stairs, scaled to *z* scores or standard deviation units) varied across the lower range of performance on the easiest task (walking, scaled using ranked percentiles). Linear regression models with quadratic terms were used to estimate change in performance on more difficult tasks across the lower half of performance on the easiest test.

RESULTS

Baseline descriptive characteristics of the study population have been previously published (18). The sample's average age was 74 years, 71.6% of participants had 12 or more years of education, 18.2% were African American, 51.2% lived alone, and 45.4% had two or more chronic diseases. For any mobility task, few women reported difficulty without reporting change in the way they did the task. For example, for walking one-half mile at baseline, 16.6% reported modification, 14.3% reported modification and difficulty, and 3.3% reported difficulty without modification.

Table 1 shows the baseline prevalences of self-reported limitation and their combinatorial patterns. As expected, dressing was the least common type of self-reported limitation, followed by transferring, then climbing, and walking one-half mile. The absence of self-reported limitation was the most common pattern (note row with "o" under each task), and occurred in 215 (43.6%) individuals, followed by self-reported limitation walking one-half mile and climbing in combination. In contrast to the expected hierarchy, the prevalence of self-reported climbing limitation alone was approximately equal to that of self-reported walking limitation alone. The hypothesized hierarchy described 334/436 (76.6%) of individuals. In other words, 23.4% of individuals reported limitation in an easier task without reporting it in all the more demanding tasks. The patterns of new-onset self-reported limitation among the 215 participants who did not report limitation at baseline are displayed in the lower half of Table 1. Again, there was a tendency toward hierarchy, with 190/215 (88.4%) of individuals fitting in a hierarchical pattern, but notably self-reported limitation in climbing occurred alone more commonly than in combination with walking one-half mile.

Spline analysis allowing break points revealed that the relationships between self-reported limitations and performance speeds were not significantly nonlinear. Model building identified depression and body mass index as covariates for final adjusted models, and there were no significant interactions.

Crude and adjusted associations between baseline performance speed and prevalent self-reported limitation outcomes are shown in Table 2. As expected, the estimated strength of association generally increased with hypothesized task demand. For example, the ORs of self-reported limitation walking one-half mile were 1.13, 1.15, 1.24, and 1.32 for performance walking, dressing, repeating chair stands, and climbing, respectively, in increasing order of demand. This pattern was not complete for the secondary outcome, self-reported limitation in two or more nonwalking mobility tasks, as a decrement in climbing speed was not more strongly associated with the outcome than was a decrement of the same proportion in a performance test hypothesized to be less demanding (dressing). In adjusted models, similar

patterns occurred. Examination of confidence intervals suggests that differences between tests of performance were not significant.

Analysis of future self-reported limitation walking one-half mile or self-reported limitation in two or more nonwalking tasks resulted in the same pattern as the cross-sectional analysis, as seen in Table 3. Sample attrition consisted of 11 deaths, which were included in analyses as competing outcomes, and 11 and 18 individuals with missing disability status for walking one-half mile and the second outcome, respectively. After exclusion of individuals with limitation at baseline, 267 and 344 individuals were analyzed for each future outcome, respectively. Tests of goodness-of-fit and model cross-validation were all consistent with models that reflected underlying data. Sensitivity analyses using the imputation described above or the outcome of persistent mobility limitation found no difference in the hierarchical tendencies of estimated associations; the only change found was that, for models of future limitation in two or more tasks, the association with slower chair stand performance reached statistical significance when imputed values were systematically inflated by +0.5 and +1 standard deviations. The ordering in the association between performance and reported limitation walking one-half mile was also replicated by results from an examination of reported limitation stooping, which was theorized to be the most demanding mobility-related task, and thus relevant to the study of early changes, and limitation climbing stairs, which is another prevalent mobility limitation. Because some researchers have raised concerns about the use of logistic regression for the calculation of risk or prevalence ratios, we confirmed the findings using Poisson models with a robust variance estimator (35).

Consistency with Fitts' theorem was evaluated by examining how standardized baseline speed (z scores, in standard deviation units) on dressing, chair stands, and climbing were related to walking speed (Figure 1). Among the slowest half of walkers, ability on tests of climbing and dressing dropped most sharply, consistent with the hypothesis that susceptible individuals were affected differentially by more demanding tests. Climbing performance showed a relationship with walking speed across the largest range of function; in contrast, the relationship between chair stands and walking was flat above the 50th percentile, and the relationship between dressing and walking was flat between the 50th and 75th percentiles. Regressing percentile speed from more difficult tests on the lower half of walking speed revealed that the curvilinear relationship displayed in Figure 1 was present for more demanding tests (quadratic p values .028 for dressing, .039 for climbing).

DISCUSSION

This study has explored whether there is a hierarchy to mobility performance. The findings partially support the hypothesis that, both in self-report and performance, the development of mobility difficulty and/or modification (aggregated as "limitation") tended to occur earlier in tasks that were more demanding. In the high-functioning group studied, most women reported mobility limitation in a hierarchical pattern. Lower extremity performance on demanding tests displayed an ordered relationship with limitation for the primary outcome, walking one-half mile, but not the secondary outcome. The association with mobility limitation generally weakened as task demand decreased, and was absent for the easiest task. These findings were supported by the extension of Fitts' theorem: Individuals who were slow walking on a flat surface (the easiest performance test) were exponentially slower on more difficult tests, suggesting that the susceptible women were differentially identified by more demanding tasks. The replication of the primary findings using either self-reported stooping or climbing limitation as outcomes suggests that there may be a shared reliance on the mechanisms behind mobility ability such that mobility is not entirely task-specific. Overall, the findings were consistent with the principle that the hierarchy of demand provides a useful general insight on the gradual development of mobility disability.

The findings do not support a strict, detailed hierarchy. For example, prevalent self-report of limitation climbing and walking one-half mile occurred in combination more often than singly. This could have been because reporting limitation for each of these tasks singly took place for a much briefer time period, because there was a mixture of less and more disabled subpopulations, or (most likely in the authors' view) because these states were approximately equal in the hierarchy of demand. Also, in analyses of the secondary outcome (self-reported limitation in two or more nonwalking mobility tasks) the dressing performance test was the strongest predictor. This finding may be related to the fact that dressing was the most complex test of performance, as it relied on stepping motions and the abilities to bend, balance, and perform gross and fine upper extremity movements.

This information has implications for targeting interventions to individuals at risk of early mobility decline during late life. It is important to tailor interventions to the needs of individuals to prevent the development and progression of late-life physical disability. These results suggest that performance in more demanding tests may be most useful in discerning risk of mobility decline among high-functioning older individuals. As examples, in this population, women in the highest quintile of speed in climbing stairs (10 steps climbed in less than 7 seconds) will likely contribute to a ceiling effect in a trial designed to prevent loss of physical function. At this top range of performance, the prevalence of individuals destined to decline in physical performance without intervention is so low that many treatments will be inappropriate due to their potential to harm or cost. Individuals with slower climbing performance would be better targets. Alternatively, the effect of an intervention in a generally high-functioning population could be missed by less demanding tests of performance.

The importance of using performance to improve targeting also relates to efforts to establish the efficacy of interventions to reverse mobility disability in older adults. For example, although many trials of progressive resistance strength training have shown positive results, approximately one third of the trials that examine disability or health status have failed to demonstrate a benefit in these outcomes. This difficulty establishing efficacy stems partly from the problem of inadequately matching interventions to individuals from a heterogeneous population (36), and may possibly be addressed by hierarchical approaches to targeting.

These findings extend prior work on potential hierarchy in the development of disability. Using varying scale items, a tendency for self-reported disability in IADLs (Instrumental Activities of Daily Living) (37) to precede ADLs has been observed by some (21–27). However, those scales are not based on a consideration of demand among physiologically related activities, unlike this analysis. IADLs and ADLs are not unidimensional and do not constitute a strict hierarchical scale (38–40).

A particularly interesting finding is that walking speed was not predictive of future limitation walking one-half mile or in two or more other mobility tasks. In this sample, 50/183 (27.3%) of women whose usual walking speed was greater than 1.0 meter/second (equivalent to above the 60th percentile, and in the normal range for healthy populations) reported limitation walking one-half mile due to health. These individuals are potential targets for interventions that aim to prevent mobility disability, and could be missed using walking speed as an indicator of risk of mobility disability. Walking speed is an important sign of physical function (8) and may be as useful as the short physical performance score in predicting more advanced, “downstream” outcomes such as ADL disability and institutionalization (13). The departure here likely results from studying smaller changes in a high-functioning population at baseline, indicating the benefit of a hierarchical approach. The implication is that, for more advanced disability outcomes, less demanding performance tests are useful; however, they are less discriminating among individuals undergoing earlier changes.

Strengths of this study include the fact that WHAS II was designed to study disability onset, and offers the ability to examine self-report in relation to an analogous test of performance. The observation of a similar pattern in self-report of mobility limitation as in objective performance measures contributes to the construct validity of the study findings. Sensitivity analyses have reduced the likelihood that missing information biases the findings, and prospective models have allowed for death as a competing factor. The use of a high-functioning sample is consistent with the theory behind this study, which argues that these findings may be different from those in a low-functioning population.

Due to limitation by gender, and because these women may be more educated and have higher rates of disease than other nationally representative samples (20), confirmation of these findings in other populations is warranted. Nonetheless, the findings here are applicable to a large proportion of older individuals. A limitation of percentile scores is that they are not immediately applicable to establishing risk cutoffs in a different population; however, the same gradient of discrimination among performance tests would be expected. The confidence intervals for the association between a 10% decline in measured performance and self-reported limitation are overlapping across different performance tests, suggesting that these associations are not statistically different between performance tests in this sample. Recent research has also demonstrated that physical disability often follows a fluctuating course (41), and this work does not suggest that mobility decline follows a single pattern. Although there may be a main pathway of mobility disability, there is considerable variation as well.

Summary

This study provides some support for the hypothesis that self-reported limitation in mobility function and performance on mobility tests tend to follow a hierarchical order in relation to demand. Future targeting of efforts to prevent or reverse mobility decline in late life may benefit from an approach that considers performance on more difficult tests, such as climbing and chair stands, to characterize risk in a high-functioning population. Walking speed alone may not be as useful as more demanding tests for risk stratification in high-functioning populations.

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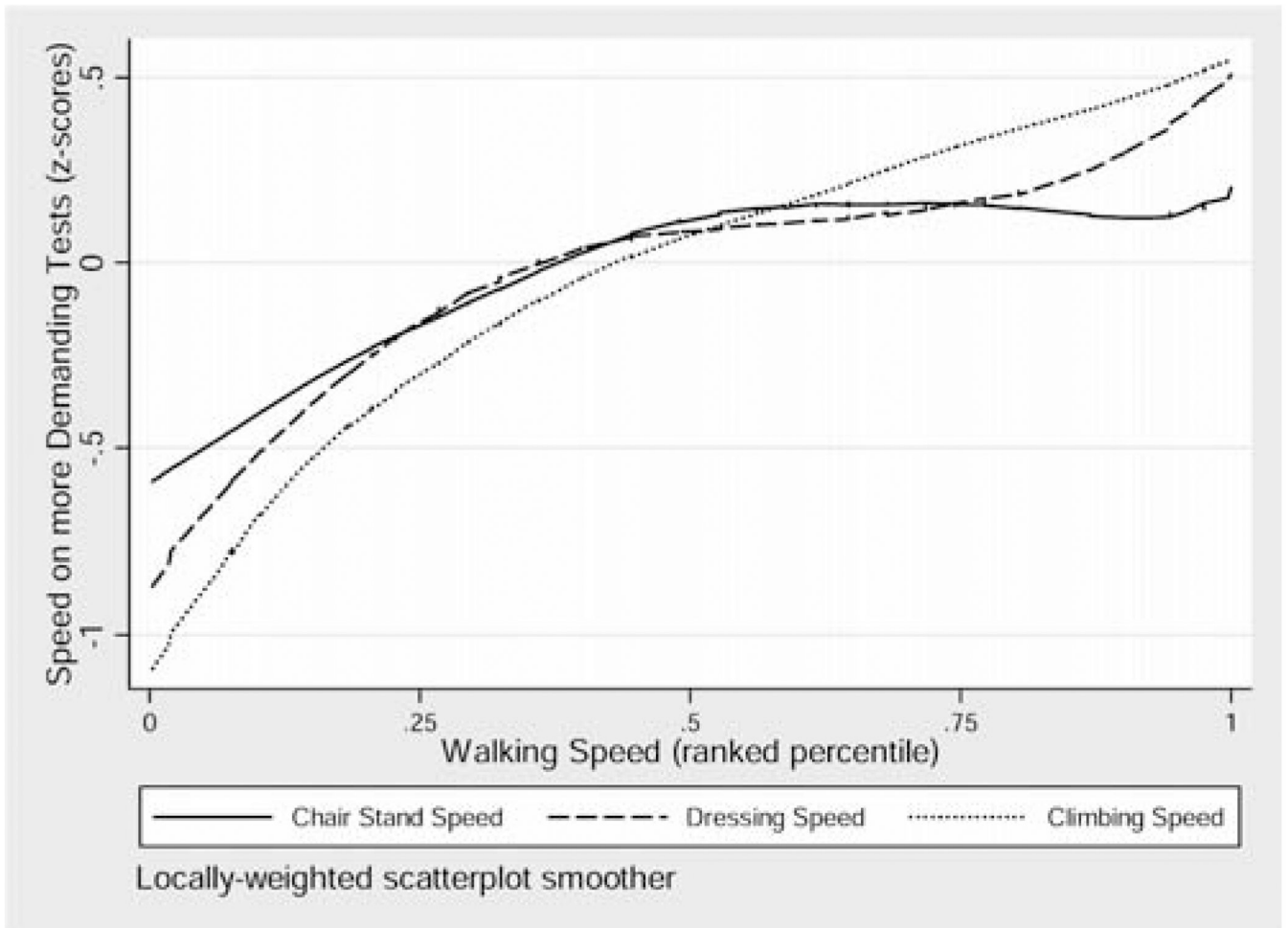


Figure 1.
Performance on hypothesized more difficult tests of mobility relative to performance walking.
z score = speed in standard deviation units, with mean equal to 0.

Table 1

Self-Report of Mobility Limitation at Baseline, by Task: Prevalent, New-Onset, and Combinatorial Patterns

Dressing	Transferring	Climbing	Walking One-Half Mile	Total
32 (7.3)	66 (15.1)	146 (33.5)	150 (34.4)	436
	Prevalence (%)			Row
	Prevalent Patterns			Frequency (%)
o	o	o	o	215 (49.3)
o	o	+	+	53 (12.2)
o	o	+	o	39 (8.9)
o	o	o	+	38 (8.7)
o	+	+	+	21 (4.8)
o	+	o	+	12 (2.8)
o	+	+	o	12 (2.8)
+	o	+	+	8 (1.8)
+	+	+	+	7 (1.6)
o	+	+	o	7 (1.6)
New Onset (%)	(at 36-month follow-up)			Total
3 (1.4)	13 (6.0)	26 (12.1)	44 (20.5)	215
New-Onset Patterns				Row
o	o	o	o	Frequency (%)
o	o	o	+	149 (69.3)
o	o	+	o	32 (14.9)
o	o	+	+	14 (6.5)
o	+	o	+	5 (2.3)
o	+	o	o	5 (2.3)
o	+	+	+	4 (1.9)

Notes: Limitation refers to task difficulty and/or modification. o = no limitation; + = limitation, to illustrate patterns combined across rows. For example, reporting limitation in climbing and walking one-half mile, but neither dressing nor transferring was the second most common pattern (53 individuals, second row); 334/436 prevalent and 190/215 new-onset cases fit within the hypothesized hierarchy. Patterns found in less than 1% of the totals (436 and 215) are included in calculations but not displayed.

Table 2

Associations Between Mobility Performance Tests and Self-Reported Mobility Limitation at Baseline:
Unadjusted and Adjusted Odds Ratios

Report of Limitation	Performance (Speed)			
	Walking (Least Demanding)	Chair Stands	Dressing	Climbing (Most Demanding)
Walking 1/2 mile (135/406 cases)				
Unadjusted OR	1.13	1.15	1.24	1.32
Adjusted OR	1.05	1.08	1.15	1.22
95% CI	0.97–1.14	1.00–1.16	1.06–1.25	1.12–1.3
<i>p</i> value	.211	.065	.001	.000
Other 2 or more mobility tasks (45/406 cases)				
Unadjusted OR	1.16	1.18	1.32	1.23
Adjusted OR	1.09	1.12	1.25	1.13
95% CI	0.97–1.23	0.98–1.28	1.10–1.43	0.99–1.29
<i>p</i> value	.152	.088	.001	.063

Notes: Limitation refers to self-reported task modification or difficulty.

Adjusted models included body mass index and depression (Geriatric Depression Score) as covariates. All Hosmer–Lemeshow chi-square goodness-of-fit and cross-validation *p* values were > .05.

OR = odds ratio for presence of limitation, versus no limitation, for a 10% decrement in speed; CI = confidence interval.

Table 3

Associations Between Mobility Performance Tests and Self-Reported Mobility Limitation at 36-Month Follow-Up Among Individuals Without Limitation at Baseline: Unadjusted and Adjusted Conditional Odds Ratios

Limitation	Performance (Speed)			
	Walking (Least Demanding)	Chair Stands	Dressing	Climbing (Most Demanding)
Walking one-half mile (62/261 cases)				
Unadjusted COR	1.10	1.17	1.21	1.27
Adjusted COR	1.04	1.14	1.15	1.22
95% CI	0.93–1.17	1.03–1.26	1.03–1.29	1.09–1.37
<i>p</i> value	.467	.011	.017	.001
Other two or more mobility tasks (23/343 cases)				
Unadjusted COR	1.09	1.17	1.40	1.14
Adjusted COR	1.07	1.16	1.33	1.15
95% CI	0.91–1.27	0.98–1.37	1.12–1.59	0.94–1.39
<i>p</i> value	.406	.094	.01	.171

Notes: All Hosmer–Lemeshow chi-square goodness-of-fit and cross-validation *p* values were > .05.

COR = Conditional odds ratios for presence of limitation, versus no limitation, for a 10% decrement in speed. CI = confidence interval.