How Do Physiological Components of Balance Affect Mobility in Elderly Men?

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- The purpose of this study was to assess the relationship between physiological components of balance and mobility in elderly men without significant disease. Our a priori hypothesis was that physical function is influenced more by accumulated modest impairments than by a single deficit. We examined 39 ambulatory men (>60 years). Subjects were classified functionally as high, intermediate, or low. Assessment included mobility functions (6-minute walk, mobility skills, reach, 10ft walk time) and physiological components of balance: sensory (vibration, proprioception, vision, vestibular), effector (ankle, knee, hip strength, range of motion), and central processing (response time to perturbations).

All mobility functions were significantly ($p < .05$) different between groups. Impairments in components of postural control were rarely different between groups: the major differences were in ankle strength and visual fields. The number of impaired domains differed across the three groups. Nineteen percent of the low group had at least three domains impaired; none of the intermediate or high groups were impaired in three domains. Fifty-six percent of the low, 20% of the intermediate, and 7% of the high were impaired in two or more domains. Variability in specific mobility measures was also predicted by the number of impaired domains. The decline in physical function may be better explained by the accumulation of deficits across multiple domains than by any single specific impairment.

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Functional decline and disability are widely feared hazards of old age. Though disability in younger persons usually has an obvious pathologic source, the basis of incapacity in the older adult often remains a mystery. One intriguing aspect of physical disability in older people is its frequency even without severe pathology. Variability in physical disability among elders is not well explained by specific diagnoses or sensorimotor impairments. In frail elders without a primary pathophysiologic loss, functional sequelae may depend more on the number and distribution of individual impairments than on any specific deficit.

This multiple-causation model of functional decline in the elderly fits well with fundamental concepts of lifespan studies, including the heterogeneity of aging and functional reserve. Heterogeneity increases with age because of the complex and variable accumulation of specific diseases, aging effects, and environmental influences. Functional reserve can be defined as excess or redundant functions not required for routine demands. Reserve declines as deficits across systems accumulate and the ability to compensate for subtle deficits diminishes.

The concept of multiple deficits causing frailty is not new. Arrays of impairments have been associated with functional deficits both in cross-sectional studies and in prospective studies of falls. The individual factors within these arrays vary widely. These inconsistent findings may be attributable at least in part to analytic method. Contributing impairments were identified from large original baseline lists by screening for association one at a time. In some cases, these factors were subsequently entered into a stepwise regression program and a final set of impairments was identified. These sets imply multiple causation but generate a new challenge: to create from this early ground-breaking work a clinical model that will be useful in geriatric evaluations.

This study examined the relationship between accumulated physiologic impairments and functional performance in elderly men using a model of components of postural control derived from existing knowledge. Specifically, we investigated the influence of accumulated subtle losses in physiologic components of postural control (sensory, effector and central processing) on mobility level as determined by the ability to negotiate stairs and to tandem walk. Subjects were divided into three groups (high, intermediate, and low) based on their performances on stairs and tandem walk. Based on our clinical judgements, our previous experience in evaluating a hierarchy of mobility skills, and our assessments of the relationships between mobility levels and falls risk, we believed the ability to climb stairs step over step and to tandem walk reflected excellent balance and a high degree of physical function and low risk for falls. Our hypothesis was that the ability to perform these physiologic functions is influenced more by accumulated modest impairments in physiologic components of postural control than by a single deficit.

METHODS

Subjects for this study were recruited from an ongoing cohort study of risk factors for falls among elderly male...
The original cohort included 310 males, whose ages ranged from 70 years to 104 years, recruited from the outpatient clinics at the Durham Veterans Affairs Hospital. Thirty-nine of the original cohort served as a sample of convenience for assessment of impairments and function. Subjects were excluded if they were unable to stand unsupported for 5 minutes, had a Folstein Mini-Mental score less than 18, or had no transportation to the VA for testing. All subjects were in stable medical health and lacked overt symptoms or impairments to account for their deficits in physical performance. Medical records were reviewed on all subjects to determine the presence of presupposed neurologic and musculoskeletal diagnoses. Several subjects carried diagnoses that implied disease but were actually mild: for example, “recovered stroke” and “early Parkinson’s disease.” The patients with mild disease did not have any overt residual symptoms (eg, hemiparesis, spasticity, rigidity).

Subjects were initially assigned to mutually-exclusive ordered mobility categories based on an established screening protocol. Low (LOW) mobility, unable to descend stairs step over step without using a handrail (n = 16); intermediate (INT) mobility, able to negotiate stairs without using a handrail but unable to tandem walk (n = 10); and high (HI) mobility, able to negotiate stairs without a railing and able to take at least five tandem steps (n = 13). Tandem walking was scored by asking subjects to take at least five tandem steps without losing their balance or stepping out of the tandem position. Following the initial screen, each patient’s sensory, central processing, effector functions, and mobility were evaluated (table 1).

Sensory function included tests of vision, proprioception, vibration, and vestibular-ocular reflexes. Subjects wore their corrective lenses during visual testing. Visual acuity was assessed binocularly with the Endstage Diabetic Retinopathy Study (EDTRS) chart at 10ft and recorded as a Snellen fraction. Contrast sensitivity was measured at a distance of 10ft using the Vistech 6500 distance contrast sensitivity system. We recorded the lowest contrast level visible at each of five different spatial frequencies using standard scoring. We used the HAP portable Visual Field Tester to measure horizontal and inferior visual fields with the subject seated. Depth perception was tested using the HAP portable depth perception apparatus at a distance of 6ft. The subject adjusted a moveable arrow with strings until he perceived that it was in line with a stationary arrow on the base. Distance between arrows (in millimeters) served as depth perception score.

Proprioception was tested at the great toe. The tester grasped the toe laterally and moved the toe either up or down a 2° or 3°. Inability to detect a few degrees of movement was considered abnormal. Further testing of proximal joints was performed if proprioception was abnormal at the great toe. Vibration sense was tested with a tuning fork beginning at the metatarsal head and moving proximally (if necessary) until the subject could immediately discriminate cessation of the vibration. We tested visual-vestibular interactions in two ways. First, with his head held stationary, the subject visually tracked the examiner’s finger while rotating his head rapidly to the right and left. The presence of corrective saccade during visual fixation in either test was considered abnormal.

We measured strength and range of motion as markers for the effector component of balance control. Bilateral ankle and knee extension/flexion strength were tested isokinetically using a Cybex II dynamometer at speeds of 60°/sec and 90°/sec, respectively. We recorded the maximum peak torque of five trials for each test. Isometric hip abduction force was measured using a Spark hand held dynamometer with the subject in side-lying position, hip abducted to 30°. Distance from the greater trochanter to the point of application of the dynamometer (approximately 2.5cm proximal to the lateral malleolus) was measured. We calculated torque (force × lever arm) for each of three trials and recorded the maximum value for data analysis. Using standardized procedures, we obtained goniometric measures of bilateral lower extremity (hip, knee, ankle) range of motion.

We examined electromyographic (EMG) responses to horizontal platform perturbations to assess central processing. Each subject stood in a comfortable, barefoot stance on a moveable platform that translated forward and backward in a random sequence. Surface EMG electrodes were placed over the quadriceps, hamstrings, gastrocnemius and anterior tibialis muscles. All subjects wore a safety harness and were guarded by an assistant to minimize the risk of falls. The method for our platform testing and EMG analysis has been previously described. EMG latencies were calculated for forward platform movement only (induced backward sway). We used the variables of tibialis anterior latency and sequence of response for data analysis. We selected the tibialis anterior latency for our marker of central processing based on our previous finding that the tibialis anterior latencies were significantly different between fallers and nonfallers.

We evaluated functional performance using the Duke Mobility Skills Test, 13 10ft walking speed, 6-minute walk, and functional reach. The Duke Mobility Skills Test is a 13-item protocol consisting of: (1) unsupported sitting for 60 seconds; (2) sitting reach; (3) chair to chair transfer; (4) picking up a ruler from the floor; (5) rising from a chair without arm support; (6) standing balance (ability to stand

| Table 1: Variables Selected to Measure Physiological Components of Balance |
|-----------------|-----------------|
| Sensory         | Vision          |
| Contrast sensitivity | Depth perception |
| Visual fields   | Somatosensory   |
| Proprioception  | Vibration       |
| Vestibular      | Central processing |
| Latency of electromyographic responses to postural perturbations |
| Sequence of muscular responses |
| Effector        | Muscle strength  |
| Range of motion |                 |

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unsupported for 60 seconds); (7) walking without or walking with an assistive device, if required; (8) stopping abruptly while walking at maximum speed; (9) 180° turning; (10) stepping over a shoe box; (11) standing reach (ability to reach at least 12 in to grasp an object; (12) ascending stairs, step over step; and (13) descending stairs, step over step. Scoring was ordinal according to the following criteria: 2 = task performed according to operational definitions of normal, 1 = performed, but abnormally and 0 = assistance required or unable to complete task. A summary score represents the total of the individual task scores.

For 10 ft walking speed, subjects were given a 3 to 5 ft warmup path, then timed with a stopwatch as they walked in their usual manner and at their usual pace for 10 ft. The number of seconds was recorded for each of two trials. Subjects then walked for 6 minutes at their usual pace on a premeasured walkway. Subjects walked continuously if able but could sit and rest at any time if needed. The total distance (in feet) covered in the 6-minute period was recorded.

Functional reach was measured using a leveled yardstick attached to the wall at the subject’s acromion height. Following procedures described previously, we obtained distance reached for each subject.\(^{15-17}\) We used the mean reach of the last three of five trials for data analysis.

Platform perturbations were performed according to previously defined protocols, using the identical equipment and data processing principles.\(^{12}\)

Our main hypothesis required that operational definitions for “impaired” sensory, central processing and effector components of balance be created. Our decision-making was based on the following precepts: (1) define “abnormal” based on clinical implications wherever possible, (2) when no clinical standard seems appropriate, dichotomize at the poorest performing quartile for the overall group, and (3) for an entire component to be declared abnormal, define a critical mass of abnormal elements that would clinically be associated with substantial compromise. All definitions were established prior to knowledge of the distributions across mobility categories. This process resulted in the definitions presented in table 2.

The criteria for the visual functions were proposed by the geriatric optometrist on the team. The peripheral sensation criteria were created by the geriatrician based solely on clinical judgement. Proprioceptive loss was believed to be a serious deficit with strong clinical implications. Vibratory loss at the ankle was considered to be a significant clinical finding because it is more likely to be associated with substantial myelinated fiber dysfunction than is vibratory loss at the great toe only. Vestibular function was tested with two tests of visual-vestibular interactions. These tests are not precise measures and were a gross screen at best of visual-vestibular interaction. The sensory component as a whole was defined as abnormal only if there were both a visual and a peripheral sensation deficit. More than one sensory deficit was required because sensory functions overlap and compensate so that a single abnormal finding may not threaten function.

Central processing was operationally defined as prolonged latency of response to perturbation. Because there are no precisely defined clinical values for normal and abnormal latencies, this variable was dichotomized at the worst-performing quartile for the whole group. The effector component included measures of peak torque about the knee and ankle. Isometric strength at the hip abductors and range of motion (ROM) across all lower extremity joints. Because a clinical definition of inadequate strength on the isokinetic dynamometer was not deemed reasonable, criteria for abnormal strength were defined based on the lowest performing quartile of all subjects. The cut-off points for abnormal range of motion was defined by the physical therapist members of the team. The requirement for an abnormal overall effector component was based on the potential for achieving clinical relevance: two muscle groups had to meet criteria for weakness or one joint had to have a substantial loss of ROM.

### DATA ANALYSIS

Analysis of variance was used to assess the differences between all continuous measures across the three mobility groups. \(\chi^2\) Analysis or Fisher’s Exact Test was used to assess the differences in distribution of categorical measures. A nonparametric test for ordinal data, the Kruskal-Wallis test, was used to assess differences in number of impaired domains across the three mobility groups. A form of logistic regression that can account for an ordinal dependent variable based on the cumulative response probabilities of the response categories, available in the statistical analysis systems (SAS) system,\(^{18}\) was used to determine the effect of number of domains on mobility level after controlling for potential confounders. General linear regression was used to assess the relationship between physical performance

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**Table 2: Definitions of Impairments**

<table>
<thead>
<tr>
<th>Sensory</th>
<th>Effectors</th>
<th>Values represent 25th percentile for measured torques of all study subjects</th>
</tr>
</thead>
</table>
| Vision       | Abnormal           | Cutoff for truncated normal distribution of categorical measures. A nonparametric test for ordinal data, the Kruskal-Wallis test, was used to assess differences in number of impaired domains across the three mobility groups. A form of logistic regression that can account for an ordinal dependent variable based on the cumulative response probabilities of the response categories, available in the statistical analysis systems (SAS) system,\(^{18}\) was used to determine the effect of number of domains on mobility level after controlling for potential confounders. General linear regression was used to assess the relationship between physical performance

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measures (reach, 10ft walk time, 6-minute walk, and Duke Mobility Skills) and the number of impaired domains.

RESULTS

The three mobility groups did not differ in age (HI 73.8 + -7.4; INT 76.2 + -5.6; LOW 75.0 + -6.6 years; p = .61). Every physical performance measure differed between the three groups: mobility skills, time to walk 10ft, functional reach, and distance traveled in 6-minute walk (table 3). For each measure, the highest functioning group performed significantly better than the low functioning group. In addition, mobility skills and walk time scores were significantly better in the intermediate than the low mobility group. Functional reach also differed between the high and intermediate groups.

The physiological components of postural control rarely differed across the three groups. Univariate assessment of all the physiological components of balance across the three groups revealed that only ankle strength and right visual fields were significantly different (p < .05) across the three groups (table 4). If mobility function is not well explained by single impairments, but rather by an accumulation of deficits, then the impairment-performance relationship may be better described by the number of affected components of postural control (table 5). The overall distribution of number of impaired components differed significantly across the three performance groups (p = .004); close to half the high functioning group had no deficits whereas only one low functioning person appeared to have no deficits in the components measured. Only one high functioning subject as opposed to over half the low functioning subjects had deficits in at least two components of postural control. Even after controlling for age and the presence of neurologic or musculoskeletal diagnoses, the number of impaired domains remained a strong predictor of mobility level (table 6).

Assessment of the variability in mobility measures (functional reach, 10ft walk time, 6-minute walk time, and Duke Mobility Skills) revealed that when controlling for age and presence of neurologic or orthopedic diagnosis, the number impaired domains was significantly related to performance (table 7).

DISCUSSION

The results of this study demonstrate that decline in functional mobility in elders without severe pathology may be better explained by the accumulation of deficits across sensory, effector, and central processing domains than by any specific common deficit. Of course in general practice, a patient may have overwhelming impairment in one sensorimotor domain that significantly affects physical function (eg, walking). For example, a patient with a severe hemiplegia has such major loss of strength that this alone could account for functional decline. More subtle changes across multiple domains explains the less obvious sources of functional decline that may previously have been attributed to age alone.

Increasing age has been associated with impairments in sensory, effector, and central processing factors. Sensory factors, including visual, proprioceptive, and vestibular function become compromised in older people. Decline in muscular strength has been documented consistently in the elderly. Accompanying the strength decline, there is a concomitant decline in range of motion and muscle flexibility. Central processing as measured by response time to postural perturbations is slower in the elderly. These effects have been attributed to aging alone but probably represent a mix of subclinical pathology, deconditioning and pure aging.

Age also affects physical function. Gait, balance, ability to negotiate stairs, and a myriad of other activities decline with age. The etiology of this decline in physical performance is of intense interest to health professionals caring for the elderly. In an epidemiological study of noninstitutionalized elderly, Jette and associates concluded that musculoskeletal and visual impairments are predictive of physical disabilities. Iverson and coworkers reported a significant association between isometric strength and the ability to balance. Lord and colleagues reported in a sample of 95 elderly individuals that postural stability is significantly associated with decline in proprioception and vibration sense of the lower extremity. As the conditions of balance were made more adverse, he demonstrated a correlation between vision (acuity and contrast sensitivity), lower extremity strength, and the ability to balance.

Physical disability in the elderly cannot be fully explained by such sensorimotor impairments or disease-specific diagnoses. In spite of the significant associations reported by Lord, he was not able to explain most of the overall variance in function. Tinetti and Ginter reported that many subjects who were impaired in basic mobility activities did not have corresponding sensorimotor impairments. The strength of the correlation between muscle strength and the ability to balance, perform stair climbing, or walk varies among studies. This variability can be expected if functional decline can be caused by many different and accumulating factors. If some elders decline due to weakness whereas others suffer due to sensory loss or delayed reaction time, then simple group statistical comparisons that test for a common shared cause are inappropriate.

The optimum way to study the association between impairment and function remains elusive. Previous approaches may have been limited because a preexisting model describing the physiologic contributors to function was not used and because univariate analysis was used to...
explain multivariate phenomena. Our study created a model and used it to describe multivariate phenomena. Recognizing that postural control and mobility are intimately related, we defined the components of postural control to be the major physiologic inputs to mobility function. Our final sample was not large enough to create a multivariate model accounting for the three major components of postural control and for interaction effects. However, we were able to test specifically for the accumulation effect. Future studies should consider ways to increase sample size so that interactive effects might be explored. A study involving a larger sample could test for three domain variables simultaneously and consider the effects of domain interactions. We suspect that in some cases there is an interactive effect of impairments across domains rather than just an additive effect.

The cross-sectional nature of this study precluded our ability to examine cause-effect relationships between imp...

Table 4: Comparison of the Physiological Components of Balance Across the Three Groups

<table>
<thead>
<tr>
<th>Sensory Vision</th>
<th>LOW</th>
<th>INT</th>
<th>HI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual contrast</td>
<td>15 ± 5.6</td>
<td>16.9 ± 6.6</td>
<td>17.7 ± 5.9</td>
<td>.46</td>
</tr>
<tr>
<td>Visual depth</td>
<td>12.3 ± 9.6</td>
<td>17.7 ± 14.9</td>
<td>8.8 ± 6.6</td>
<td>.11</td>
</tr>
<tr>
<td>Right visual field</td>
<td>62.2 ± 14.7</td>
<td>72.6 ± 18.1</td>
<td>80.2 ± 8.5</td>
<td>.02*</td>
</tr>
<tr>
<td>Left visual field</td>
<td>71.5 ± 9.4</td>
<td>75.2 ± 19.2</td>
<td>82.6 ± 8.1</td>
<td>.06</td>
</tr>
<tr>
<td>Infrared visual field</td>
<td>59.4 ± 14.7</td>
<td>60.6 ± 14.1</td>
<td>69.6 ± 18.3</td>
<td>.09</td>
</tr>
<tr>
<td>Proprioception or vibration (percent abnormal)</td>
<td>25%</td>
<td>20%</td>
<td>7.7%</td>
<td>.22</td>
</tr>
<tr>
<td>Vestibular</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
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</table>

Table 5: Number of Domains of Postural Control That Were Impaired Across the Three Groups

<table>
<thead>
<tr>
<th>Number of Impaired Domains</th>
<th>Number and Percentage of Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LOW</td>
</tr>
<tr>
<td>None</td>
<td>1 (6)</td>
</tr>
<tr>
<td>One</td>
<td>6 (37.5)</td>
</tr>
<tr>
<td>Two</td>
<td>6 (37.5)</td>
</tr>
<tr>
<td>Three</td>
<td>3 (19)</td>
</tr>
</tbody>
</table>

\( p = .004 \) by Kruskal-Wallis test for ordinal data.

* Definitions of impairments for each of the variables are explained in table 2.

Table 6: Logistic Regression (Analysis of Maximum Likelihood Estimates)

<table>
<thead>
<tr>
<th>Variable</th>
<th>( x^2 )</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of domains</td>
<td>9.13</td>
<td>.0025</td>
</tr>
<tr>
<td>Age</td>
<td>.11</td>
<td>.73</td>
</tr>
<tr>
<td>Neurologic diagnosis</td>
<td>.05</td>
<td>.81</td>
</tr>
<tr>
<td>Musculoskeletal diagnosis</td>
<td>2.21</td>
<td>.13</td>
</tr>
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Table 7: General Linear Regression Model of Physical Performance Measures

<table>
<thead>
<tr>
<th>Physical Performance Measure</th>
<th>Number of Impaired Domains</th>
<th>Age</th>
<th>Neurodiagnosis</th>
<th>Orthodiagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>p</td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td>Functional reach</td>
<td>15.4</td>
<td>0.0004</td>
<td>0.84</td>
<td>0.37</td>
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<tr>
<td>10ft walk time</td>
<td>3.26</td>
<td>0.079</td>
<td>0.19</td>
<td>0.665</td>
</tr>
<tr>
<td>6min walk time</td>
<td>6.63</td>
<td>0.014</td>
<td>0.17</td>
<td>0.687</td>
</tr>
<tr>
<td>Duke mobility skills</td>
<td>13.95</td>
<td>0.0001</td>
<td>0.24</td>
<td>0.546</td>
</tr>
</tbody>
</table>

References
34. Woolacott MH. Gait and postural control in the aging adult. In: Bles...
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