Association between sensorimotor function and functional and reactive balance control in the elderly

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Abstract

Objectives: postural disturbances can arise from performing functional tasks and from external perturbations. Identification of sensorimotor factors associated with both types of balance control in the elderly can help us to understand better the balance problems facing older adults.

Design: cross-sectional.

Subjects: healthy young, stable older, and functionally unstable older adults with 16 participants in each group.

Methods: clinical vibration sense and muscle strength of the lower extremity, and functional balance (FB) tests were conducted. The timing and amplitude of the reactive postural muscle responses of the leg postural muscles, recorded from standing subjects following support surface backward translation, were also examined.

Results: young and older subjects differed significantly in the amplitude of their postural muscle responses, while the two older groups differed significantly in muscle strength and FB. When age was controlled, the strength of the ankle dorsiflexors was the only significant predictor for FB. For reactive postural muscle responses, none of the sensorimotor factors was significant.

Conclusion: functional and reactive balance abilities differed in their associating factors. The difference in the patterns of association for functional and reactive balance implies the need for separate assessment for these two categories of balance control clinically.

Keywords: ageing, somatosensation, muscle strength, postural control, functional balance, elderly

Introduction

Postural disturbances can be introduced externally or internally in daily living and frequently impose threats to standing balance. To maintain standing balance, the ability to detect postural disturbances and generate proper postural responses is required. This ability has long been noted to deteriorate with increasing age, and could possibly lead to imbalance and increased risk of falling [1, 2].

Extensive research has been devoted to determining the underlying causes of imbalance in the elderly. Deterioration in the function of the somatosensory and motor systems occurs with ageing, and has been found to be related to poorer static standing balance [3–5]. Activities involving functional balance control, such as bending or lifting, have been found to have no or only poor association with vibration sense [6]. The performance of the above tasks was also not related to the strength of the leg muscles [6], but walking speed, chair rising and stair climbing were [7, 8]. Strong associations have also been reported between ankle strength and the results of clinical global functional balance tests [9].

In addition to maintaining balance while performing daily activities, the ability to counteract unexpected externally induced imbalancing forces, i.e. reactive postural control, is also essential for independent living. This aspect of balance control can be tested by inducing body sway in standing subjects by sudden support surface translation [10, 11]. Changes in postural responses following support surface translation were found to occur with ageing and could possibly lead to
Informed consent was obtained from all the participants. They underwent a neurological screening test with a neurologist. The status, history of falling, and self-perceived balance were assessed. Participants answered questionnaires regarding their general health and found to correlate significantly with quantitative measures of sensory function [25]. The sum of the grades from the three test sites was used for data analysis.

**Methods**

**Subjects**

Subjects were recruited by local newspaper advertisement. A total of 16 young females and 65 independent community-dwelling older females participated in the study. These participants did not have (i) neurological disorders, (ii) musculoskeletal disorders or pain that interfered with their daily activities, (iii) joint replacement in the lower extremity, (iv) diabetes mellitus, (v) peripheral neuropathy, or (vi) uncontrolled high blood pressure (>160 mmHg) or orthostatic postural hypotension. These exclusion criteria served to select a sample that consisted of healthy older adults of different levels of balance ability, and whose sensorimotor function was not affected by specific diseases. All the participants answered questionnaires regarding their general health status, history of falling and self-perceived balance, and underwent a neurological screening test with a neurologist. Informed consent was obtained from all the participants.

**Subject classification**

Two objective balance tests, the Berg Balance Scale and Dynamic Gait Index test, and one subjective balance test of self-perceived balance ability, were used to assess the level of functional balance. These tests rate different aspects of balance ability and have been shown to have good reliability and validity [19, 20]. The details of subject classification have been presented previously in related articles [13, 16]. Briefly, the mean balance scores obtained from the 65 older adults were regarded as population means for the purpose of group assignment. It was determined a priori that the older adults who had at least two balance test scores that fell above the upper quartile scores of the population would be classified as stable older adults (SOA) and those who had at least two test scores that fell below the lower quartile scores would be classified as functionally unstable older adults (FUOA). The balance test scores of the 65 older adults showed that the upper quartile cut-off scores were 56, 24 and 94, and the lower quartile scores were 54, 21 and 81, for the Berg Balance Scale, Dynamic Gait Index test, and self-perceived balance test, respectively. As a result, 16 older adults were classified as stable older adults and another 16 as functionally unstable older adults.

**Muscle strength and somatosensation evaluation**

Muscle strength of the flexors and extensors of the hip, knee and ankle was tested using manual muscle testing following standardised procedures [21]. The strength was graded based upon a 5-level categorical scale ranging from zero to normal, with plus and minus subscales, resulting in a total of 12 ranks. The means of the two legs were used for data analysis. Manual muscle testing is widely used in clinical settings to assess muscle strength and has been reported to have high inter-rater reliability [22, 23]. A 256 Hz standard tuning fork was used to test the vibration sense of the big toe, lateral malleolus and tibial tuberosity of both legs to represent somatosensation [24]. A 3-level scale, with 0 indicating no sensation, 1 indicating impaired sensation and 2 indicating normal, was used for grading. Timely and correct responses to sensory stimulation were recorded as ‘normal’. Delayed or inconsistent responses were recorded as ‘impaired’. Incorrect responses or inability to perceive sensory stimulation would be recorded as ‘absent’. Although the inter-rater reliability of a 3-scale tuning fork vibration sense test has not been tested statistically, this test is a widely accepted clinical tool for the assessment of sensory function, and is believed to be reliable and found to correlate significantly with quantitative measures of sensory function [25]. The sum of the grades from the three test sites was used for data analysis.

**Balance tests**

The Berg Balance Scale was used to reflect the global functional balance ability. This test rates performance from 0 (cannot perform) to 4 (normal performance) on 14 different tasks involving functional balance control, including transfer, turning and stepping [20]. To reflect reactive balance control, the postural response characteristics of the leg muscles to external balance threats were used. Subjects, standing on a customised movable force platform that was driven by a motor to generate sudden translational movement, were asked to remain upright without moving the legs or arms in response to support surface perturbations. Backward support surface translation at a movement amplitude of 5 cm and velocity of 40 cm/s was used. The postural muscle activation characteristics in response to support surface translations in the medial gastrocnemius (MG) and biceps femoris (BF) were detected using surface electrodes recorded at 500 Hz. The EMG signals were low-pass filtered (100 Hz) and stored for off-line analysis. The EMG variables of interest were muscle contraction onsets and integrated EMG (IEMG) over 70–150 ms after perturbation onset, which were determined by interactive customised computer algorithms. To facilitate between-group comparisons of the integrated EMG (IEMG), the IEMGs were normalised to the baseline IEMG during a 100 ms quiet standing period prior to each platform perturbation.
All the sensorimotor and Berg Balance tests were conducted by two experienced physical therapists who had received special training for the purpose of this research. Each assessor tested about half of the young and older subjects.

### Data analysis

A computer software package, SPSS for Windows (Release 10.0, SPSS Inc., Chicago, USA), was used for statistical analyses. Independent t-tests were used to test the age differences between the two older groups. Comparisons between the three groups were made using one-way analysis of variance (ANOVA) for vibration sense and the Berg Balance Scale, and separate multivariate ANOVAs for reactive postural muscle responses (EMG onset and amplitude), and leg muscle strength. Follow-up univariate and post hoc Bonferroni tests were conducted as indicated. Pearson correlation analyses were conducted to determine the relationship among the variables. In order to determine what sensorimotor factors best predicted balanced postural response characteristics, regression analyses were conducted separately for the Berg Balance Scale, and onset and amplitude of the MG and BF induced by support surface perturbation. The independent variables included the strength of the six leg muscle groups, and vibration sense. Age was entered as a co-variate. A blockwise regression model was used to enter the independent variables hierarchically, in the order of age, leg muscle strength and vibration sense. An alpha-level greater than 0.05 was considered significant.

### Results

#### Between-group comparisons

Sixteen older adults were classified into stable and functionally unstable groups. Functionally unstable older adults had an average of 0.6 falls within 6 months prior to the experiment, which was significantly more than the young adults’ zero (P<0.001) and the stable older adults’ 0.06 falls (P<0.003). The difference in the number of falls between the stable older and young adults was not statistically significant. The two older groups did not differ significantly in age (P=0.09, Table 1). One-way ANOVA showed that the unstable group scored significantly lower in the Berg Balance Scale than the young and stable older groups (both P<0.001), while the latter two groups did not differ significantly (Table 1).

In reactive postural muscle responses, MANOVA showed significantly smaller EMG amplitudes in the leg and thigh muscles in older adults, compared with those in young adults, while the two older groups did not differ significantly (Table 2). The onset timing did not show significant between-group differences (Table 2).

The vibration sense was significantly different between the young and the functionally unstable groups (P=0.016), but not between other groups. For the lower extremity muscle strength, it was found that the functionally unstable group had lower strength than the other two groups in all the muscles (Table 1). The differences were statistically significant, except for knee flexion where the differences between the two older groups were non-significant (Table 2). Stable older adults only differed from young adults in the strength of the hip and knee flexors.

### Analysis of association

Pearson correlation analyses showed that, except for the postural muscle onset timing, age was significantly correlated with all the measures: increasing age associated with poorer balance, smaller IEMG and weaker muscle strength. The Berg Balance Scale was significantly related with vibration sense (r=0.446, P=0.002) and the strength of all the six lower extremity muscle groups (r=0.507–0.768, all P<0.001). Regression analysis shows that age had a significant but small contribution, explaining about a quarter of the variance. When the strength of the ankle plantarflexors was added, the age effect became insignificant, and yielded a markedly higher r². The strength of the ankle dorsiflexors was also significant, and added a small increase in r². Vibration sense did not emerge as a significant factor (Table 3).

Postural muscle response amplitudes were significantly related to hip and knee strength. Regression analysis showed that age was the only significant contributor, explaining about a quarter of the variance (Table 3). The onset latencies were not related to any of the sensorimotor measures, and no significant regression model emerged.

### Discussion

Identification of sensorimotor factors associated with balance control in the elderly can provide crucial information for the development of therapeutic strategies for the prevention of and intervention in imbalance and falling. In this study, when age was controlled, the strength of the ankle muscles was a strong predictor for a clinical global functional balance, while none of the sensorimotor factors significantly predicted reactive postural muscle responses.

The Berg Balance Scale was developed specifically to measure functional balance ability of older adults and

### Table 1. Means and standard deviations for subject characteristics, functional balance scores, and muscle strength

<table>
<thead>
<tr>
<th>Item</th>
<th>YA</th>
<th>SOA</th>
<th>FUOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>24.9 (4.1)</td>
<td>73.5 (5.8)</td>
<td>76.2 (4.8)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.63 (0.04)</td>
<td>1.56 (0.07)</td>
<td>1.59 (0.04)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>63 (8.6)</td>
<td>61.9 (7.8)</td>
<td>71.1 (14.7)</td>
</tr>
<tr>
<td>Berg Balance Scale</td>
<td>56 (0)</td>
<td>55.9 (0.34)</td>
<td>54.4 (2.2)</td>
</tr>
<tr>
<td>Hip Extb</td>
<td>14.7 (0.7)</td>
<td>13.8 (1.6)</td>
<td>11.4 (1.8)</td>
</tr>
<tr>
<td>Hip Flxb</td>
<td>14.9 (0.5)</td>
<td>13.4 (1.6)</td>
<td>12 (1.3)</td>
</tr>
<tr>
<td>Knee Extb</td>
<td>15 (0)</td>
<td>14.8 (0.7)</td>
<td>13.9 (1.1)</td>
</tr>
<tr>
<td>Knee Flexb</td>
<td>14.9 (0.5)</td>
<td>13.2 (1.4)</td>
<td>12.4 (1.2)</td>
</tr>
<tr>
<td>Ankle PFb</td>
<td>15 (0)</td>
<td>14.4 (1.2)</td>
<td>10 (2.8)</td>
</tr>
<tr>
<td>Ankle DFB</td>
<td>15 (0)</td>
<td>15 (0)</td>
<td>14.4 (0.9)</td>
</tr>
</tbody>
</table>

The two older groups differed significantly in Berg Balance Scale, but not in age. YA, young adults; SOA, stable older adults; FUOA, functionally unstable older adults; Ext, extension; Flx, flexion; PF, plantarflexion; DF, dorsiflexion.

Statistically significant between YA and FUOA, and between SOA and FUOA.

Statistically significant between FUOA and other 2 groups.

Statistically significant between YA and SOA.
and knee flexors. The small sample size (the age differences were non-significant, except for the hip weaker strength in the stable older adults than young adults, and stable older adults. In spite of a consistent trend of functionally unstable older adults, but not between young

cition in muscle strength [3, 28, 29]. In this study, the differ-
ence in muscle strength was significant between young and functionally unstable older adults, but not between young and stable older adults. In spite of a consistent trend of weaker strength in the stable older adults than young adults, the age differences were non-significant, except for the hip and knee flexors. The small sample size ($n=16$ each group) might contribute to the lack of age effect.

In addition to functional balance ability, this study also examined reactive postural muscle responses, which showed significant age but not functional differences. Similar findings have also been reported previously showing that older adults of different balance abilities (fallers versus non-fallers) differed markedly in muscle strength but not necessarily in reactive postural muscle response characteristics [30].

In response to externally imposed postural disturbances, the timing and amplitude of postural muscle responses need to be scaled to the size of the perceived imbalance [13, 31]. This process involves reception and integration of sensory inputs, selection of response strategies, and execution of postural responses [32]. Muscle strength, which is related to response execution, would become a limiting factor only when the required strength exceeds the person’s capacity [33, 34]. The perturbations used in this study were medium in size and all subjects were able to successfully recover balance without difficulty. It is probable that when larger balance threats are used, the role of muscle strength could become more prominent.

The marked contrast in the patterns of association between muscle strength and functional and reactive balance control abilities underlies the importance of testing reactive balance clinically. A functional balance test result, such as the Berg Balance Scale, does not necessarily coincide with the individual’s ability to deal with external balance threats. Physical impairments, such as muscle strength, may not be sufficient to predict the changes in this ability either. The level of ability of reactive balance control in the elderly thus needs to be specifically assessed before interventions can be developed.

Similar to muscle strength, somatosensation is also one of the physiological components related to balance control. The current study found that vibration sense was not a significant predictor for functional or reactive balance control. Substitution of Ia afferent input (activated by vibration) with visual, vestibular, or other somatosensory inputs has been attributed to the incongruity between the loss of a particular sensory modality and the extent to which balance performance was

### Table 2. Between-group multivariate analysis of variance (MANOVA) comparisons in reactive postural muscle responses, and muscle strength

<table>
<thead>
<tr>
<th>Muscle response</th>
<th>Wilk's $\lambda P$</th>
<th>Univariate $P$</th>
<th>YA versus SOA</th>
<th>YA versus FUOA</th>
<th>SOA versus FUOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>0.002</td>
<td>0.003</td>
<td>0.018</td>
<td>0.007</td>
<td>0.76</td>
</tr>
<tr>
<td>MG</td>
<td>0.008</td>
<td>0.014</td>
<td>0.036</td>
<td>0.999</td>
<td></td>
</tr>
<tr>
<td>BF</td>
<td>0.062</td>
<td>0.511</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onset</td>
<td>0.209</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>0.001</td>
<td>0.122</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Hip Ext</td>
<td>0.001</td>
<td>0.009</td>
<td>0.001</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>Hip Flex</td>
<td>0.001</td>
<td>0.404</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Knee Ext</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.069</td>
</tr>
<tr>
<td>Knee Flx</td>
<td>0.001</td>
<td>0.589</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Ankle PF</td>
<td>0.001</td>
<td>1</td>
<td>0.001</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Ankle DF</td>
<td>0.001</td>
<td>0.804</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant group main effect between young and older groups was found in muscle activation amplitude in reactive postural responses. Group main effect was also significant for differences in muscle strength between age and stability groups. MG, medial gastrocnemius; BF, biceps femoris.

### Table 3. Regression analysis for functional and reactive balance tests

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Factors</th>
<th>Accumulative $r$</th>
<th>$R^2$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berg Balance Scale</td>
<td>Age</td>
<td>0.501</td>
<td>0.251</td>
<td>0.287</td>
</tr>
<tr>
<td></td>
<td>Ankle PF</td>
<td>0.792</td>
<td>0.627</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Ankle DF</td>
<td>0.897</td>
<td>0.804</td>
<td>0.001</td>
</tr>
<tr>
<td>Postural muscle</td>
<td>Age</td>
<td>0.504</td>
<td>0.254</td>
<td>0.001</td>
</tr>
<tr>
<td>response</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplitudes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MG</td>
<td>Age</td>
<td>0.576</td>
<td>0.332</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Onset</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF</td>
<td>Age</td>
<td>0.048</td>
<td>0.002</td>
<td>0.761</td>
</tr>
<tr>
<td></td>
<td>Onset</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Independent variables (3 blocks) include age (co-variate), strength of six leg muscle groups, and vibration. Age and strength of the ankle dorsiflexors and plantar-flexors were significant predictors for functional balance. Age was the only significant predictor for the response amplitude of both muscles in reactive balance tests. MG, medial gastrocnemius; BF, biceps femoris.
affected [14, 35, 36], and could probably explain the lack of association between vibration sense and balance performance. In conclusion, functional and reactive balance abilities not only differ in their control mechanisms, but also in their associating factors. Muscle strength was found to be a strong predictor of functional but not reactive balance performance. The difference in the patterns of association for functional and reactive balance implies the need for separate assessment tools for these two categories of balance control clinically.

Key points
- Identification of sensorimotor factors associated with balance control in the elderly can help us to better understand balance problems facing older adults.
- For functional and reactive balance performance, their associating factors were not identical, and thus would need to be assessed separately in clinical management.

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28. Clement FJ. Longitudinal and cross-sectional assessments of age changes in physical strength as related to sex, social class, and mental ability. J Gerontol 1974; 29: 423–9.
Driving cessation in patients attending a memory clinic

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Abstract

Background: driving is an increasingly important form of transport for older people. Dementia is common in later life and will eventually lead to driving cessation, which reduces the public health risk of impaired driving but also impairs access to services. The factors associated with driving cessation in dementia are uncertain.

Objective: to examine the demographic, psychometric and personal factors associated with driving cessation in patients attending a memory clinic in a European setting.

Design, subjects and setting: a retrospective study of 430 consecutive patients referred over a 21 month period to the memory clinic at a university teaching hospital.

Methods: the data collected included a questionnaire administered to their carers regarding demographic and personal factors as well as driving practices. All subjects had standardised neuropsychological and functional assessments. Dementia diagnosis was recorded using DSM IV criteria.

Results: driving cessation in this population was associated with poorer cognitive and functional status, older age, and living in the city. Of those studied, 22% continued to drive: 63% of these were driving daily, 71% were driving unaccompanied and 31% reported an accident. There was no difference in the neuropsychological testing between those who reported an accident and those who did not report an accident.

Conclusions: driving cessation was affected not only by psychometric performance but also by demographic and personal factors.

Keywords: automobile driving, cognitive disorders, dementia, aged, elderly

Introduction

Driving is increasingly the primary mode of transportation for older people. This is illustrated by the fact that the greatest relative increase in licence holding between 1965 and 1985 in the UK was amongst the older age group [1] and this trend is expected to continue. Older people also regard driving as an important skill. In those aged 55 or over, 77% of drivers perceive driving as essential or very important [2]. Furthermore, most available alternatives to car driving are less safe for older persons who frequently do not regard public transport as an adequate alternative.