The Effects of Two Types of Cognitive Tasks on Postural Stability in Older Adults With and Without a History of Falls

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Background. This study used a dual task design to investigate the effects of two different types of cognitive tasks on stability (as measured by center of pressure displacement) in young vs older adults with and without a history of falls.

Methods. Two secondary cognitive tasks, a sentence completion and a visual perceptual matching task, were used to produce changes in attention during quiet stance under flat vs compliant surface conditions in 20 healthy young adults, 20 healthy older adults, and 20 older adults with a history of imbalance and falls. Postural stability was quantified using forceplate measures of center of pressure (COP). Speed and accuracy of verbal response on the cognitive tasks were also quantified.

Results. During the simultaneous performance of a cognitive and postural task, decrements in performance were found in the postural stability measures rather than the cognitive measures for all three groups. While no differences were found between the young adults and the older healthy adults on the firm surface, no task condition, when task complexity was increased (either through the introduction of a secondary cognitive task, or a more challenging postural condition such as standing on the compliant surface), significant differences in postural stability between the two groups became apparent. In contrast to the young and healthy older adults, postural stability in older adults with a history of falls was significantly affected by both cognitive tasks.

Conclusion. Results suggest that when postural stability is impaired, even relatively simple cognitive tasks can further impact balance. Results further suggest that the allocation of attention during the performance of concurrent tasks is complex, depending on many factors including the nature of both the cognitive and postural task, the goal of the subject and the instructions.

Previous research has shown that many aspects of postural control decline with age, and that postural deficits are a contributing factor to an increased likelihood for falls in many older adults (1-10). Several studies have suggested that decreased balance control either due to injury (11) or aging (12) may increase the attentional requirements associated with maintaining stability. But there has been little research clarifying the possible mechanism by which declining postural control requires increased attentional resources, nor the effect of increased attentional resources on the ability to maintain stability during the concurrent performance of postural and cognitive tasks.

It is possible that as adults age, increased attention is used to compensate for deterioration within a sensory system. Numerous studies have documented age-related changes in peripheral sensory structures in all three sensory systems important for postural control (13-18). Researchers have hypothesized that as sensory systems deteriorate with age, increased attention is allocated to "heighten" the signal coming from these systems in order to gain the necessary information for postural control (12,19). Thus, this is one possible mechanism by which declining postural control increases attentional demands in older adults.

Using a dual-task paradigm, researchers have begun to study the attentional demands associated with sensory motor processing for postural control. Several researchers have documented that even highly practiced tasks such as sitting, standing, and walking require some cognitive processing, and have found that the degree of processing varies with the postural task (20,21). Thus, static equilibrium tasks such as sitting or standing quietly appear to require less attention than do dynamic equilibrium tasks such as walking (20-23).

When the task of maintaining postural stability is done concurrently with another task, which task will receive a higher priority with respect to allocation of attentional resources? Researchers have shown that when a focal voluntary movement task is performed during unsupported quiet stance (a postural stability task), the focal movement is delayed long enough to ensure the activation of anticipatory postural adjustments which make certain that stability is preserved (24,25). If external support is provided, reducing the stability demand of the postural task, the reaction time for the secondary motor task is shortened (24). This suggests that when there is a competition between two motor tasks, one of which is postural control, the maintenance of stability is the priority. One might presume that this same
principle, "posture first," applies in all dual task conditions. Thus, when a person is engaged in a combination of both cognitive and postural tasks, attention would be allocated to postural control ensuring stability and potentially affecting performance on the cognitive task. Stelmach et al. (12) found that recovery from postural instability induced by rapid arm swinging was unaffected by the concurrent performance of a secondary mental arithmetic task in young adults, but was impaired in elderly subjects. These results support the "posture first" hypothesis in young adults but raise the possibility that the priorities for allocating attention during the performance of dual tasks may change as people age.

Maki and Whitelaw (26) found that postural responses in both young and older adults were affected by the simultaneous performance of a secondary mental-arithmetic task because subjects tended to lean slightly forward. Teasdale et al. (27) found that both young and elderly subjects had slower reaction times to an auditory stimulus when sensory information from either vision or somatosensory systems for postural control was decreased. This research does not support a "posture first" hypothesis, because the concurrent performance of a cognitive task did affect postural stability and this effect was enhanced in older adults. Little is known about the effect of competing cognitive and postural demands on attentional resources during the performance of multiple tasks in older adults with a recent history of falls. We hypothesize that changes in attention associated with the performance of concurrent secondary cognitive tasks would affect postural stability more in older adults with a history of falls, compared to healthy young and older adults. We believe that this competition for limited attentional resources during the simultaneous performance of postural and cognitive tasks contributes to instability and falls in some older adults.

In order to test this hypothesis, we used a dual task paradigm to investigate the effects of two types of cognitive tasks on postural stability in young adults and older adults with and without a history of falls. The two cognitive tasks chosen, a language vs a visual spatial task, were designed to examine the effect of two different types of information processing on postural stability. Two postural tasks included standing on a firm vs compliant foam surface. Both postural control and spatial orientation require visual processing; however, it is not clear whether visual pathways used for information processing are the same for both tasks. We hypothesized that the greatest interference between cognitive and postural tasks in our experimental paradigm would be during the performance of a visual spatial orientation task while standing on a compliant surface because of the competition for visual processing pathways in the two tasks. It has been suggested that standing on compliant foam decreases the availability of reliable somatosensory cues for postural control resulting in an increased reliance on visual and vestibular inputs for maintaining stability (28).

**METHODS**

**Subjects**

We tested 20 young adults (mean age 31 ± 6), 40 older adults, 20 with a self-reported history of falls (mean age 78 ± 8), and 20 without (mean age 74 ± 6). Subjects were volunteers from the Seattle community who responded to a newspaper advertisement. Criteria for classifying older adults as fallers included: self-report of two or more falls in the previous 6 months in the absence of a known neurological or musculoskeletal diagnosis. We did not systematically determine the cause of previous falls, hence type of fall was not used as a criterion for inclusion or exclusion in this study. Table 1 displays the baseline characteristics for each of the three groups. The two groups of older adults were comparable with respect to age, gender, marital status, living situation, and mental status. Performance on the Short Portable Mental Status Questionnaire (SPMSQ) (29) was used to determine mental status. Frequency of imbalance, defined as near falls, slips, trips, or stumbles experienced by the subject, was determined by self-report.

The decision to recruit and classify older adults based on prior history of falls was based on the assumption that people with a history of recent recurrent falls would most likely have impaired balance. This assumption was then verified by testing balance abilities directly in all subjects. Results from the clinical testing, shown in Table 2, found that older adults with a previous history of falls had significantly lower test scores (p < .05) on all clinical tests of balance compared to the older adults with no history of falls, supporting the assumption that the two groups had significantly different balance skills.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Young Adults</th>
<th>Older Nonfallers</th>
<th>Older Fallers</th>
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<tbody>
<tr>
<td>n</td>
<td>20</td>
<td>20</td>
<td>20</td>
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<tr>
<td>Age — yr</td>
<td>31 ± 6</td>
<td>74 ± 6</td>
<td>78 ± 8</td>
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<tr>
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<tr>
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<td>10 (50)</td>
<td>None</td>
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<tr>
<td>Sex</td>
<td>Female — n (%)</td>
<td>11 (55)</td>
<td>13 (65)</td>
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<td>Age</td>
<td>11 (55)</td>
<td>9 (45)</td>
<td>7 (35)</td>
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<tr>
<td>Living Situation — n (%)</td>
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<td>14 (70)</td>
<td>20 (100)</td>
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<td>Home</td>
<td>Retirement center (independent)</td>
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<tr>
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<td>20 (100)</td>
<td>18 (90)</td>
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<td>No deficit (0-2 errors)</td>
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<td>20 (100)</td>
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<td>5 (25)</td>
<td>8 (40)</td>
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<td>7 (35)</td>
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Clinical tests of balance and mobility. — Following informed consent procedures as approved by the Institutional Review Board at Northwest Hospital, Seattle, all subjects underwent an assessment of balance and mobility skills. This included measures to document functional abilities related to balance and mobility, assess underlying sensory and motor strategies critical for these skills, and to determine potential sensory and motor impairments contributing to instability and gait impairments (30). Subjects provided a medical history and a self-report of fall and balance history. Subjects then completed the SPMSQ (29) and the Balance Self-Perceptions Test, a short questionnaire in which subjects rate their perceived confidence when performing common activities of daily living. Subjects were asked to rate (using a scale 1–5) their degree of confidence in performing 20 basic activities of daily living (ADLs) and instrumental activities of daily living (IADLs) without fear of loss of balance (31). The questionnaire was a modification of one developed by Tinetti et al. (32) in their study examining the relationship between fear of falling and measures of basic and instrumental ADLs.

A total of four clinical tests were chosen to evaluate functional balance and walking skills. The Berg Balance Scale (33) rates balance during the performance of 14 tasks including sitting, standing, reaching, leaning over, turning, and stepping. The Three-Minute Walk Test requires subjects to walk at their preferred pace for 3 minutes over a 300-foot indoor course (30). The course is carpeted and involves four different turns. Balance and gait deviations were scored using the Performance Oriented Mobility Test (6). The Dynamic Gait Index was used to evaluate the ability to adapt gait to changes in task demands including changing speeds, head turns in the vertical or horizontal direction, stepping over or around obstacles, and stair ascent and descent (30). All clinical tools have been shown previously to have good inter-rater and test-retest reliability.

Cognitive tasks. — Two secondary cognitive tasks, Sentence Completion (34), a language processing task, and Judgment of Line Orientation (JOLO; 35,36), a perceptual matching visual task, were used to produce changes in attention during the performance of a concurrent postural task. In the JOLO task the subject is presented with an array of lines numbered 1 to 11 set at different orientations. Above the array are two unnumbered lines set at the same orientation as two of the numbered array. Subjects are required to pick the two numbers that correctly identify the orientation of lines. In the Sentence Completion task the subject is presented with four blanks, some of which have a letter preceding them. The subject is required to create a four-word sentence by replacing each blank with a word. When a letter precedes the blank, the word must start with that letter; any word may be used in the blanks with stars. Thus, in the example "*b* f" an appropriate response would be "the boy ran fast."

Cognitive tasks were presented on a Macintosh computer placed at eye level with reference to the subject. A tape recorder placed 12 inches from the subject was used to record verbal responses to the cognitive tasks. Subjects were instructed to stand as still as they could and complete as many sentences (or line orientations) as possible within a 30-sec period. As soon as one sentence (or line orientation) was completed, the examiner triggered the next stimulus. Performance on cognitive tasks was determined by scoring both speed (number of responses completed within 30 sec) and accuracy. Accuracy on each trial of the JOLO task was determined by whether or not the subject correctly identified the numbers which matched the orientation of the two target lines presented. Thus, for each trial completed, subjects could score 0, 1, or 2 points. Final overall accuracy was calculated as the ratio of number correct divided by total number of possible points (e.g., 2 for each trial completed). Accuracy on each trial of the Sentence Completion task was a function of both correctly using cued starting letters and creating a grammatically correct sentence. One point was assigned for each word meeting criteria and 2 points were assigned for the sentence being grammatically correct. Thus, for any sentence completed, there was a possibility of receiving 0 to 6 points. In our example, the sentence "the boy ran fast" would receive 6 points, "she baked some cookies" would receive 5 points, and "the boy more fun" would receive 4 points. Final accuracy was calculated as the ratio of number of points received divided by total number of possible points (i.e., 6 for each sentence completed). Change in performance on the cognitive tasks in the two postural conditions was compared across the three groups.

Postural conditions. — Changes in center of pressure in the two surface conditions, firm vs compliant (medium density 2-inch Temper Foam) were used to examine postural stability when there was competition between postural and cognitive tasks. Center of pressure (total distance traveled) was used as a measure of postural stability in stance. Figure 1 shows our experimental set-up. Subjects were instructed in the two cognitive tasks, Judgment of Line Orientation (JOLO) and Sentence Completion (Sentences), while sitting. Subjects then performed two 30-sec trials of each cognitive task while standing with feet shoulder distance apart, hands
COGNITIVE DEMANDS AND POSTURAL CONTROL

at side of body, on a firm or compliant surface. Subjects also stood for two trials on firm vs compliant surface in a no task context. Task order was randomized. Instructions to the subjects were to stand as still as possible and complete as many responses as possible within the 30-sec period.

**Apparatus.** — The apparatus consisted of a static force platform (Balance Master, NeuroCom, Clackamas, OR) which measured force and moment components along the x, y, and z axes. The signals were amplified and bandpass filtered from 0–10 Hz (12 bits analog/digital conversion, 50 Hz sampling rate). Displacement of the center of pressure was then computed and presented as total distance traveled in mm for each 30-sec trial.

**Analysis**

Displacement of the center of pressure (distance traveled in mm over 30-sec trial) was used to quantify postural stability in the six conditions, firm surface/no task, firm surface/JOLO task, firm surface/sentence task, compliant surface/no task, compliant surface/JOLO task, compliant surface/sentence task. Four of the older adults with a history of falls (18%) lost their balance and were caught to prevent a fall during at least one condition on the compliant surface. In order to include their data, the distance traveled during the period in which they were able to maintain their balance was determined and extrapolated to the full 30 sec. We conducted separate analyses removing the 4 subjects who could not perform at least one trial on the compliant surface. No differences in the overall results were found when these subjects were removed; thus analyses are reported utilizing the full sample.

Descriptive statistics were used to characterize the subject sample; subjects were grouped according to fall history. A multivariate analysis of variance (MANOVA) was used to analyze this factorial mixed design (37,38). Pearson correlation was used to assess the relationship between clinical measures of balance and mobility and postural sway under the dual task conditions (39).

**RESULTS**

**The Effect of Concurrent Cognitive Task on Postural Stability**

Following initial investigation of the data, square root transformation of the raw displacement of center-of-pressure data was conducted to ensure homogeneity of variance, normalize the distributions, and reduce the impact of outlying scores (40). Multivariate analysis of variance of these transformed data revealed several significant effects including main effect of group (F = 17.66, p < .0001), main effect of surface (F = 143.52, p < .001), a Surface X Group interaction (F = 7.19, p < .001), a main effect of task (F = 44.38, p < .001), and a Task X Group interaction (F = 11.79, p < .05). The interaction between the within-subject factors was not significant, nor was the triple interaction of Group X Surface X Task. Given the finding of significant interactions between the within- and between-subject factors, simple main effects were investigated next (37,39).

The effect of surface. — Given the interaction of Group with Surface, the effect of Group was examined in each surface independently (averaging across tasks). On the firm surface, there were no significant differences found between young adults and the healthy older adults, but the older adults with a history of falls differed significantly from both of these groups (p < .05, utilizing Scheffe multiple range tests). On the compliant surface there were significant differences in postural stability between all three groups (p < .05, utilizing Scheffe multiple range tests), with the older adults with a history of falls exhibiting the most instability, and the younger adults being the most stable. Figure 2 shows the effect of surface on postural stability (averaged across the three task conditions) in the three groups. All groups displayed a similar pattern of performance, showing significantly more instability on the compliant than on the firm surface; the stability of the older adults with a history of falls was most affected (p < .001 for all groups utilizing paired t-tests).

The effect of task. — Given the interaction of Group with Task, the effects of Group were examined for each task in-
dependently (averaging across surfaces). Again, using Scheffé multiple range tests, analyses revealed that in the no-task condition, there was no significant difference in stability between the young adults and the older healthy adults; however, the older adults with a history of falls swayed significantly more than either of the other two groups. The addition of either the JOLO or Sentences tasks produced a significant difference in stability among the three groups (p < .05). The older adults with a history of falls exhibited the most instability, while the younger adults were the most stable. Figure 3 shows the effect of task (averaged across surface) for all three groups.

Utilizing planned comparisons (37), the pattern of performance across tasks within each group was examined. This analysis revealed that the pattern of performance across tasks was similar for the young adults and older adults without a history of falls. Neither of these groups had significant differences in stability between the no-task and JOLO conditions, but did sway significantly more during the Sentences task (F = 22.15, p < .001; F = 24.09, p < .001, respectively). In contrast, in the older adults with a history of falls, both JOLO and Sentence Completion significantly increased sway over the no-task condition (F = 5.48, p < .03; F = 29.26, p < .0001, respectively) with the greatest increase in postural instability found during performance of the Sentences task. These results can also be seen in Figure 4, which shows the increase in center-of-pressure displacement during the performance of the Sentences task in two older subjects, a nonfaller and one with a history of falls. These results are inconsistent with the hypothesis that the greatest interference between cognitive and postural tasks in our experimental paradigm would be during the performance of a visual spatial orientation task (JOLO) because of the competition for visual processing pathways in the two tasks.

The Effect of Postural Demands on Cognitive Performance

Figure 5 presents the number of responses completed on the two cognitive tasks, on the firm vs compliant surface for all three groups. Results indicate that young people were significantly faster (number of responses completed within 30 sec) at both tasks than either older group. No differences were found between the two groups of older adults on speed of performance on either cognitive task. There was no significant effect of surface condition on number of responses completed for either cognitive task.

Figure 6 presents the percentage of correct responses on the two cognitive tasks, on the firm vs compliant surface for all three groups. Compared to the two groups of older adults, young adults showed significantly more correct responses on the JOLO task but not the Sentence Completion task. There was no significant difference in number of correct responses between the two groups of older adults. There was no significant effect of surface condition on number of correct responses for any of the groups.

Relationship Between Clinical Measures and Dual Task Performance

For all conditions there was a high correlation between performance on clinical measures of balance and mobility, and center-of-pressure displacement in the dual task conditions in the older adults. Correlations ranged from −.4194 to −.8351; all correlations were significant (p < .0001). Among our older adults, those who scored the poorest on the clinical measures of balance and mobility also had the largest displacement of center of pressure in the dual task conditions.
Figure 4. Comparison of displacement of the COP during a no-task vs Sentence Completion task in an older adult with no history of falls and an older adult with a history of falls.

Figure 5. The number of responses completed on the two cognitive tasks in the firm vs compliant surface for all three groups.

Figure 6. The percentage of accurate responses on the two cognitive tasks, in the firm vs compliant surface for all three groups.
DISCUSSION

This study used a dual task design to investigate the effects of two different types of cognitive tasks on stability (as measured by center-of-pressure displacement) in young vs older adults with and without a history of falls. Our results found that stability did not significantly differ between the young adults and the healthy older adults. This is consistent with other authors who have shown either no difference or only marginal difference in stability between young adults and healthy older adults (7,8). It is the older adults with a history of falls who consistently show significant impairments in stability whether standing on a firm or compliant surface. While stability in all three groups decreased when standing on the compliant surface, the older fallers were most affected, suggesting that changing the availability of somatosensory inputs for postural control was most challenging for the older fallers.

We had hypothesized that when two tasks require the same processing pathways there should be a decrement in performance on one of the tasks when they are performed simultaneously. Thus, one would expect that the greatest interference between cognitive and postural tasks in our experimental paradigm would be during the performance of a visual spatial orientation task (JOLO) while standing on a compliant surface because of the competition for visual processing pathways in the two tasks. Results from our experiment found that the greatest interference was between the sentence completion task and the task of standing on a compliant surface. This could be due to the fact that while the sentence completion task is a language task, it was presented visually, thus placing some demands on visual processing pathways. It is possible that auditory pathways alone been used for the processing of this task, less interference on the control of postural stability would have occurred. Another possibility is that the JOLO task performance could be enhanced by maintaining vertical stability; thus, maintaining postural stability would have been important for both the stability and accurate task completion.

While no differences were found between the young adults and the older healthy adults on the firm surface/no-task condition, when task complexity was increased either through the introduction of a secondary cognitive task or a more challenging postural condition, differences between these two groups began to emerge. This can be seen in the significant decrease in stability in the healthy older adults compared to the young adults during stance on the compliant surface. While there was no significant difference in stability between the two groups during performance of the visual perceptual matching task (JOLO), there was during the performance of the Sentence Completion task. In contrast, postural stability in older adults with a history of falls was significantly affected by both the visual perceptual and language tasks.

These results suggest that when postural stability is impaired (as in the elderly fallers), even relatively simple cognitive tasks can further impact balance. It is also possible that other factors could account for the differences between the two older groups. In addition to significant differences in balance abilities, the group of fallers tended to be older, took more medications, had more comorbidities, and scored lower on the SPMSQ test, compared to the group of non-fallers. Thus, it may be that differences in health and mental status, rather than balance per se, could account for differences between the two groups. In addition, since the faller group had a larger percentage of females than the nonfaller group, gender bias may have contributed to group differences.

Contrary to our original hypothesis, our results suggest that during the simultaneous performance of a cognitive and postural task, decrements in performance were found in the postural stability measures rather than the cognitive measures. Interestingly, increasing the difficulty of the postural tasks (standing on a compliant surface) did not significantly impact performance on the cognitive tasks. We had hypothesized that in a dual task context, allocation of attention would be directed toward maintaining stability at the expense of cognitive performance. We referred to this as a "posture first" hypothesis, suggesting a hierarchy exists in the allocation of attentional resources with posture being a first priority. Our data do not support the hypothesis that posture is hierarchically more important than the performance of these secondary tasks, since during the performance of concurrent tasks, the decrement was found in postural stability rather than in the cognitive measures in all three groups. We do not believe, however, that this finding would be constant across all postural conditions. It is possible that the conditions used in this study were not challenging enough to require a change in priorities so that postural control is ensured even at the expense of cognitive performance. The threat of injury was quite small. Subjects could simply take a step to prevent a fall, or were caught by one of the researchers.

We thus suggest a modification to the "posture first" attentional hierarchy. We suggest that the allocation of attention during the performance of concurrent tasks is complex, depending on many factors including the nature of both the cognitive and postural task, the goal of the subject, and the instructions. In situations where the threat of injury is great (e.g., walking on an icy street or standing at the edge of a cliff), postural control would be the first priority for attentional resources. However, we suggest that in many situations the threat to stability is not so clear cut. In situations where stability is not potentially injurious, performance on a secondary task could then take priority.

We think that hierarchies exist in both cognitive and postural tasks with respect to the degree of attentional demands. This is consistent with results from other researchers (20-23) who suggest that attentional demands increase with the difficulty of the postural tasks. For example, sitting, standing, and walking represent a postural hierarchy with respect to attentional demands. In a dual task context, when postural demands on attentional resources are low, cognitive tasks that are similarly low in attentional demands may not affect postural stability, but more demanding cognitive tasks might. This can be seen by the deterioration in postural stability during the performance of the Sentence Completion task in comparison to the visual processing (JOLO) task, which did not affect stability. However, when postural demands are high (either due to the sta-
bility requirements inherent in the task being performed or because the individual has a limited capacity to maintain postural stability either due to aging or disease), even relatively nondemanding cognitive tasks might adversely affect postural stability. Again, this can be seen in the adverse effect on stability of both cognitive tasks in the older adults with a history of falls.

Balance retraining programs designed to reduce the likelihood for injurious falls in older adults have focused primarily on modifying many of the sensory and motor impairments affecting postural control (31,41-43). The results of this study provide an increased understanding of attentional demands associated with declining postural control, and their effect on stability when additional cognitive tasks are being performed. This increased understanding could serve as a basis for the development of new balance retraining programs that focus on training stability under the context of multiple tasks. The multiple level of hierarchy in both postural and cognitive tasks could be exploited by the clinician when developing sequential tasks designed to challenge and improve balance. Initially, tasks that are low on the postural hierarchy could be retrained; as balance improves, secondary cognitive tasks of varying difficulty could be introduced to further challenge balance and enhance the development of postural stability.

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