Case Report

Training of Balance Under Single- and Dual-Task Conditions in Older Adults With Balance Impairment

Background and Purpose. Traditionally, rehabilitation programs emphasize training balance under single-task conditions to improve balance and reduce risk for falls. The purpose of this case report is to describe 3 balance training approaches in older adults with impaired balance. **Case Descriptions.** Three patients were randomly assigned to 1 of 3 interventions: (1) single-task balance training, (2) dual-task training under a fixed-priority instructional set, and (3) dual-task training under a variable-priority instructional set. **Outcomes.** The patients who received balance training under dual-task conditions showed dual-task training benefits; these training benefits were maintained for 3 months. The patient who received variable-priority training showed improvement on novel dual tasks. **Discussion.** Older adults may be able to improve their balance under dual-task conditions only following specific types of balance training. This case report gives insight on how this intervention might be combined with more traditional physical therapy intervention. [Silsupadol P, Siu KC, Shumway-Cook A, Woollacott MH. Training of balance under single- and dual-task conditions in older adults with balance impairment. *Phys Ther.* 2006;86:269–281.]

Key Words: *Aging, Balance, Posture, Rehabilitation.*

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Falls, the leading cause of accidental death among older adults, are a serious clinical problem among adults over 65 years of age.[1–6] Falls are costly and have potentially devastating physical, psychological, and social consequences. Nonfatal falls often lead to physical injury (eg, fractures), reduced levels of activity, loss of confidence, and altered lifestyle in elderly people.[5,7,8]

Although most falls involve multiple factors, causes of falling are often categorized into intrinsic (personal) and extrinsic (environmental) factors.[9,10] Some examples of intrinsic factors include balance impairment, neurological disorders, sensory deterioration, musculoskeletal disorders, postural hypotension, and medication use.[2,5–7,11–13] Examples of extrinsic factors include ill-fitting footwear, poor lighting, slippery surfaces, and inappropriate furniture.[2,5,7,14] Research shows that balance impairment is a major contributor to falling in elderly people.[2,7,8,13,15]

Over the past 20 years, a considerable amount of research has been conducted to determine the relationship between balance control and motor or sensory system function in order to understand the causes of falling and to create effective strategies to prevent falls in elderly people. Tang and Woollacott[16] investigated age-related changes in postural responses to a forward slip. It was shown that balance control was reduced in elderly people compared with young people. They exhibited longer onset latencies to distal muscle responses, disruptions in the temporal organization of postural muscle responses, and longer agonist/antagonist coactivation duration when they were given external threats to balance.[16] Moreover, it has been shown that balance deteriorates in elderly people when sensory inputs contributing to balance control are reduced.[17,18] This supports the idea that balance depends on both motor and sensory system functions. In recent years, however, it has become increasingly apparent that other neural systems, including cognitive resources, may contribute to balance control.[19–23]

This case report describes 3 approaches to training balance—single task, dual task with fixed-priority instructions, and dual task with variable-priority instructions—in 3 older adults with balance impairment.

The dual-task method, which requires participants to perform multiple tasks simultaneously, has been used to investigate the effect of cognitive tasks on postural control and vice versa. It has been shown that the ability to maintain postural stability is reduced when performing 2 or more tasks concurrently and these deficits are increased in elderly people with balance impairment.[19,20,22,24–27] Recent research suggests that older adults who perform poorly under dual-task conditions are at increased risk for falls.[28–31] Additional research has shown that, with a simultaneous walking and talking task, participants were found to either stop walking or take a longer time to complete their gait task.[32,33] These findings confirm the notion that balance performance is influenced by simultaneously performing a cognitive task.

Older adults with balance impairment are frequently referred for physical therapy to improve balance control and reduce the risk of falling. Although activities of daily living often require maintaining balance during the performance of several concurrent tasks, balance is most often trained under single-task conditions. Single-task training involves practicing functional tasks requiring balance (eg, standing, walking, and transfer) in isolation. In an effort to increase the challenge to balance during the performance of a functional task, the therapist may vary the conditions under which the patient practices—for example, changing the availability of sensory cues (eg, reduce visual cues by asking the participants to close their eyes or practice in dim lighting) or support surface conditions (eg, walking on a flat surface versus an inclined surface).[34–38] In light of research

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Ms Silsupadol, Dr Shumway-Cook, and Dr Woollacott provided concept/idea/project design and writing. Ms Silsupadol and Mr Siu provided data collection and project management. Ms Silsupadol provided data analysis. Junko Halterman provided patients, and Jennifer Van De Hey and Janet Hollander provided facilities/equipment. Laura Vearrier, PT, PhD, provided consultation (including review of manuscript before submission).

This article was received April 8, 2005, and was accepted July 11, 2005.

indicating that inability to perform concurrent tasks is a contributing factor to instability and falls in many older adults, it has been suggested that training balance under both single- and dual-task conditions is necessary to optimize functional independence and reduce falls in elderly people.[28–31]

Although research on the effect of balance training under dual-task conditions is limited, the results from research by Kramer et al[39] using non–balance-related tasks support the benefits of training under dual-task conditions in older adults. Kramer and colleagues used a monitoring task in conjunction with an alphabet-arithmetic task to examine the effects of the training strategies on dual-task performance. They described the training strategy as follows: "The monitoring task required participants to monitor six continuously changing gauges and to reset each gauge as soon as it reached the critical region by pressing one of six keys on a computer keypad. An alphabet-arithmetic task required participants to add and subtract numbers from letters (eg, k−3=h), and they were also required to compare the answer on the current trials with the response on the previous trial, indicating the greater or lesser letter by typing it on the computer keyboard using an upward or downward pointing arrow."[39(p57)] "Part-task" training as defined by Kramer and colleagues involved practicing individual tasks separately (single-task conditions). In contrast, "whole task" training involved practicing both tasks simultaneously (dual-task conditions). According to task coordination and management theory, part-task (single-task) training has fewer processing demands compared with whole-task (dual-task) training. However, part/single-task training does not allow the participant to practice coordinating the 2 tasks that are performed concurrently. In contrast, whole/dual-task training allows for the practice of multi-task coordination.[39]

Kramer and colleagues[39] also compared the effectiveness of whole/dual-task training under various sets of instructions (fixed priority [FP] versus variable priority [VP]). In the FP condition, participants were asked to place the same amount of attention on both tasks at all times, whereas, in the VP condition, attention was switched between tasks. The results showed increased accuracy of the task and decreased verbal response time with VP training compared with FP training. The dual-task training benefits were larger in dual-task conditions than in single-task conditions, and improvement after training using VP instructions also could be generalized to other dual tasks that are not directly trained. The research by Kramer et al[39] served as a model for the 3 types of intervention described in this case report.

Despite the potential importance of dual-task balance training for fall prevention in older adults, no research studies have examined the effects of training balance under single-task versus dual-task (FP versus VP) conditions in older adults. Therefore, the purpose of this case report is to describe 3 approaches to training balance—single task, dual task with FP instructions, and dual task with VP instructions—in 3 older adults with balance impairment. The present data are intended as a pilot study for an upcoming study.

Case Descriptions

History

All 3 patients were older adults who volunteered for balance training because of a self-reported history of falls in the previous year or because of a concern about impaired balance. None of the patients reported a history of neurological or musculoskeletal diagnoses that could account for possible imbalance, such as cerebrovascular accident, Parkinson disease, cardiac problems, transient ischemic attacks, lower-extremity joint replacements, or significant visual and auditory impairments. All 3 patients were able to walk 9 m (30 ft) without the assistance of another person and were able to follow simple instructions. Their Mini Mental State Examination (MMSE) scores were greater than 24. Table 1 summarizes the patients' demographic characteristics. Prior to participation, each patient provided informed consent in accordance with the Human Subjects Compliance Committee of the University of Oregon.

Examination

Clinical measures. The Berg Balance Scale (BBS),[40] the Dynamic Gait Index (DGI),[41] and the Timed "Up & Go" Test (TUG)[42] measured balance and mobility under single-task conditions; the TUG was repeated under dual-task conditions. A stopwatch and tape measure were used for data collection. The BBS is a 14-item test that quantifies performance, using a 4-point ordinal scale, on tasks such as standing up, standing with eyes open or closed, or standing with feet together. Scores range from 0 to 56, with high scores suggesting better balance. Research has demonstrated a strong relationship between the BBS scores and fall risk in older adults.[41] Psychometric properties reported on the BBS include an interrater reliability intraclass correlation coefficient (ICC) of .98, a test-retest reliability correlation coefficient (ICC) of .98, and an internal consistency (Cronbach alpha) of .96.[40] The concurrent validity was measured by using the correlation between BBS scores and scores on other clinical measures including the Barthel Index of Activities of Daily Living (r=.67), TUG Test (r=−.76), and the balance subscale of the Tinetti Performance-Oriented Mobility Assessment (r=.91).[40]

Table 1.
History and Interview Findings

	Patient 1 Single Task	Patient 2 Dual Task–Fixed Priority	Patient 3 Dual Task–Variable Priority
Age (y)	82	90	93
Sex	Male	Female	Female
Living environment	Retirement center alone	Private home alone	Retirement center alone
Physical activity	Walking 5 times/week—30 min	Walking daily—30 min	Sitting exercises 3 times/week—1 h
Gait assistive device	Independent	Independent	Independent with straight cane
No. of falls (the previous year)	1	1	2
Frequency of loss of balance without a fall	5 times/year	Once a month	3 times/week
How did the fall/imbalance occur?	Walking and turn the head quickly, get up quickly	Turn and get up quickly	Walk and talk simultaneously, walk on the narrow path

The DGI rates performance from 0 (poor) to 3 (excellent) on 8 different gait tasks, including gait on even surfaces, gait when changing speeds, gait with head turns in a vertical or horizontal direction, and gait when stepping over or around obstacles and on steps. Scores on the DGI range from 0 to 24. The DGI has been shown to have interrater reliability of .96, test-retest reliability of .96,[43] and concurrent validity with the Berg Balance Test (correlation between DGI and BBS is .67).[41]

For the TUG, time required to stand up from a 43.18-cm (17-in) chair, walk 3 m, turn, walk back, and sit is recorded. In the TUG under dual-task conditions, patients were asked to give a response to continuous simple addition/subtraction questions (such as 3+2=5, 6−2=4) while they were doing the TUG task. Researchers[42] have found a correlation between TUG scores and other measurements, such as gait speed (r=−.61) and the Barthel Index (r=−.78). The TUG was shown to have a sensitivity and specificity of 87% for identifying older adults who are prone to falls.[33]

Patients also completed the Activities-specific Balance Confidence Scale (ABC)[44] and the MMSE.[45] The ABC Scale was used to determine self-reported confidence when performing 16 different daily activities without an assistive device, using a confidence rating scale (0%=no confidence, and 100%=full confidence). The ABC Scale was found to be a predictor for fall status.[46] Test-retest reliability (r) was estimated to be .92, and internal consistency (Cronbach alpha) to be .96.[46] The concurrent validity was measured by using the correlation between the ABC Scale score and the physical abilities subscale score of the Physical Self-Efficacy Scale (r= −.63).[44] The MMSE evaluates general cognitive ability, including orientation to date, registration (immediate recall), attention and calculation, recall of 3 words, and language, with a score of 24 suggesting decreased cognitive ability (eg, dementia). The MMSE has been shown to have a good test-retest reliability with the same (r=.887) or different (r=.827) examiners.[45] The correlation (r) between the MMSE and the Wechsler Adult Intelligence Scale was .78 for Verbal IQ and .66 for Performance IQ.[45] One researcher did all of the testing; thus, interrater reliability testing was not performed on the clinical measures used in our project.

Laboratory measures. Each patient was asked to walk 4 m under 6 different conditions, 2 of which were performed under single-task conditions and the remaining 4 under dual-task conditions. The single-task conditions were: (1) narrow walking and (2) obstacle crossing; the dual-task conditions were: (1) narrow walking while counting backward by "threes," (2) obstacle crossing while counting backward by threes, (3) narrow walking with tone discrimination, and (4) obstacle crossing with tone discrimination. For the narrow walking tasks, the patients were asked to walk between 2 strips of tape secured to the floor that ran parallel the length of the walkway. The width of the distance between the 2 strips of tape was determined by measuring their preferred step width with a tape measure and subtracting 4 cm. We chose 4 cm because it resulted in a stance width that was achievable by an older adult with balance impairments, yet it was narrower than normal walking. The number of missteps (steps onto or outside the tape) was counted during the testing period.

For the obstacle crossing tasks, the patients were instructed to walk and step over an obstacle (a shoe box: 10 cm high×19 cm wide×33 cm long) that was placed at the 2-m mark. For the counting backward by threes, the patients were asked to walk counting backward by threes from any starting number from 90 to 200 simultaneously with either narrow walking or obstacle crossing. The total number of subtractions completed during the counting backward task and the accuracy of the responses were recorded. For the tone discrimination task, the patients were asked to respond if an auditory tone was high or low while simultaneously performing either narrow walking or obstacle crossing.

Three-dimensional motion analysis (Peak Performance System)* was used to calculate body kinematics during performance of the tasks. Reflective markers were placed bilaterally on the second metatarsal head, lateral malleolus, lateral femoral epicondyle, greater trochanter, and humeral head.[47] The location of the body center of mass (COM) was calculated by using data derived from the 6-camera (frontal and sagittal views) and reflective marker systems. The marker trajectory data were collected at 120 Hz and low-pass filtered using a fourth-order Butterworth filter with a cutoff frequency of 6 Hz.

The displacement of the mediolateral COM was calculated under all 6 conditions. Increased displacement of the mediolateral COM (>6 cm) is associated with increased risk for falls among community-dwelling older adults.[48]

Clinical and laboratory measurements, performed at the Motor Control Laboratory at the University of Oregon, were collected before and after training. In addition, selected clinical measurements were repeated during the second week of training in order to examine interim balance change and at 12 weeks following the end of training to test retention. Patients were evaluated by one physical therapist and trained by another physical therapist. Each patient spent about 1 hour for clinical testing and 1½ hours for laboratory testing.

Patient 1. Patient 1 was an 82-year-old man. Observational gait analysis (performed as the patients walked along with the physical therapist to the testing room on the first appointment) revealed that he walked very fast and his step lengths were short. He reported feeling unsteady when asked to walk slowly and while turning his head rapidly to talk with the physical therapist walking behind him. He repeatedly stopped walking when talking.

His BBS score (52/56) revealed postural instability with tasks requiring a reduced base of support. He scored 24/24 on the DGI, suggesting good postural control under dynamic (eg, gait on even surfaces and gait when changing speed) conditions. He was more unstable under dual-task conditions, with increased time on the TUG under dual-task conditions compared with the time on the TUG under single-task conditions. He had a high level of confidence in his balance performance (93/100% on the ABC Scale), and he scored 30/30 on the MMSE.

Patient 2. Patient 2 was a 90-year-old woman. Observational gait analysis suggested normal gait speed and step and stride lengths. She reported feeling unsteady when walking up and down stairs without using a rail, and she stopped repeatedly when walking and talking. In addition, she would not turn her head toward the person talking to her, preferring to maintain a head-forward orientation.

She scored 48/56 on the BBS, demonstrating instability during single-leg and tandem stance. She scored 21/24 on the DGI; instability was observed during walking with head turns in both horizontal and vertical directions and while walking up and down stairs. Patient 2 took an additional 3 seconds to complete the TUG under dual-task conditions compared with the TUG under single-task conditions. She had a high level of confidence in her balance performance (86% on the ABC Scale). She scored 27 out of 30 points on MMSE, indicating that she had normal cognitive ability.

Patient 3. Patient 3 was a 93-year-old woman. She used a cane in her right hand and walked with a wide base of support; her gait speed was quite slow. Her step and stride length were normal. She reported feeling uncomfortable during prolonged standing, while walking on a narrow path, and while talking when walking. She frequently stopped walking during conversations. Although she could walk 9 m (30 ft) without any assistive device, she reported increased confidence when using a cane or walker. She preferred using a walker when she had to maintain her balance in the difficult situations (eg, reaching and grasping a book on the tall bookshelf) and when she walked inside her room, whereas she preferred using a cane when she walked outside her room.

Postural instability was observed during performance of clinical tests. She scored 33/56 on the BBS, having the most difficulty with the dynamic tasks and when base of support was reduced. On the DGI, she scored 18/24, with instability noted when changing gait speed, when walking around or over an obstacle, and when walking up and down stairs. Instability was particularly evident under dual-task conditions. She required more time to complete the TUG under dual-task conditions compared with the TUG under single-task conditions. Patient 3 scored 83/100% on the ABC Scale, suggesting that she had high confidence in her balance performance with an assistive device. Poor dual-task performance could not be attributed to impaired cognition because she scored 29 out of 30 points on MMSE, suggesting that her cognitive ability was good. Tables 2 and 3 summarize the clinical and laboratory findings for all 3 patients.

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Table 2.
Clinical Findings of Balance Measurement at Before Training, the Second Week of Training (Interim), After Training, and 12 Weeks Following the End of Training (12 Weeks)[a]

	Patient 1				Patient 2				Patient 3			
	Before Training	Interim	After Training	12 Weeks	Before Training	Interim	After Training	12 Weeks	Before Training	Interim	After Training	12 Weeks
BBS (0–56)	52	NT	55	56	48	NT	51	55	33	NT	48	NT
DGI (0–24)	24	NT	24	24	21	NT	23	23	18	NT	21	NT
TUG-S (s)	7.91	6.53	6.79	6.16	9.63	9.53	8.82	9.55	15.95	13.02	12.02	NT
TUG-D (s)	8.80	6.97	8.02	6.97	12.44	11.25	10.2	9.27	20.82	17.12	14.52	NT
ABC (0–100%)[b]	93	NT	97	97	86	NT	87	85	83[c]	NT	88[c]	NT
No. of CB (NW)[d]	5.2	NT	6.4	NT	5	NT	6.6	NT	5.6	NT	6.2	NT
No. of CB (OC)[d]	5.8	NT	6.4	NT	5	NT	5.2	NT	4.2	NT	6	NT

[a] BBS=Berg Balance Scale, DGI=Dynamic Gait Index, TUG-S=Timed "Up & Go" Test under single-task condition (average of 3 trials), TUG-D=Timed "Up & Go" Test under dual-task condition (average of 3 trials), NT=not tested. Patient 1 received single-task training, patient 2 received dual-task training with a fixed-priority instructional set, and patient 3 received dual-task training with a variable-priority instructional set.
[b] ABC=Activities-specific Balance Confidence Scale without assistive device for patients 1 and 2.
[c] Patient 3 refused to complete the ABC unless she could imagine herself with her cane.
[d] CB=the average number counted backward by "threes" over 5 trials performed simultaneously with narrow walking (NW) and obstacle crossing (OC), respectively.

Table 3.
Measurements of Mediolateral Center of Mass Displacement Under 6 Conditions Collected on a Three-Dimensional Motion Analysis System Before and After Training[a]

	Patient 1		Patient 2		Patient 3	
	Before Training	After Training	Before Training	After Training	Before Training	After Training
Narrow walking (cm)	2.6	3.5	4.2	5.6	7.5	7.7
Obstacle crossing (cm)	6.1	4.6	7.1	10.4	14.0	11.6
Narrow walking+counting backward (cm)	3.2	4.5	5.7	4.7	7.9	8.1
Obstacle crossing+counting backward (cm)	4.6	4.8	9.7	9.1	18.7	14.6
Narrow walking+tone discrimination (cm)	2.6	3.5	5.3	5.8	7.1	5.8
Obstacle crossing+tone discrimination (cm)	4.5	3.5	9.5	8.4	15.2	12.0

[a] Patient 1 received single-task training, patient 2 received dual-task training with a fixed-priority instructional set, and patient 3 received dual-task training with a variable-priority instructional set.

Evaluation

Commonalities among the 3 patients included postural instability as revealed by clinical and laboratory tests, which was more pronounced when the base of support was reduced (feet together) and under dual-task conditions. Severity of balance impairment varied by patient. The postural instability with a reduced base of support could be related to degeneration of the motor and sensory systems during the aging process. The postural instability under dual-task situations might be associated with an age-related reduction in their ability to manage or coordinate multiple tasks. Balance training under single-task conditions has been shown to be effective in improving balance ability under single-task contexts in elderly people.[43,49] Thus, balance training under single-task conditions (eg, maintaining stance stability under varying sensory and base of support conditions) should result in improved balance under these conditions. If the ability to maintain balance under dual-task conditions in elderly people depends on their ability to manage and coordinate multiple tasks, however, single-task balance training might not result in improved balance in a dual-task context. It has been shown that dual-task performance abilities (in non–balance-related tasks) could be improved by asking the patients to perform both tasks together and shift priorities between performance of the 2 tasks.[39] Thus, this framework was used for training balance under dual-task conditions.

Intervention

All patients participated in 45-minute balance training sessions 3 times a week for 4 weeks. The duration and frequency of this training were chosen because previous studies have shown that a 10- to 12-hour balance training program was effective in improving balance performance in elderly people.[49,50] Balance training sessions followed Gentile's taxonomy of movement tasks, a theoretical framework for retraining motor control.[51] This framework progresses patients from: body stability, to body stability plus manipulation, then body transport, and finally body transport plus manipulation.

Examples of body stability tasks included quiet standing (with usual and reduced base of support), standing with eyes closed, tandem standing, recovery of standing following manual perturbations, and standing on compliant or moving surfaces. Examples of body stability plus manipulation tasks included standing on compliant surfaces while holding a glass of water, tandem standing with rapid alternating hand movement, standing and reaching in all directions, and throwing and catching a ball while standing. Body transport tasks included walking (with usual and reduced base of support), walking backward, walking sideways, and walking under dim light conditions. Lastly, tasks for body transport plus manipulation included repeating body transport tasks while carrying a mug or a basket or while tossing a ball. Training was completed in a closed environment (a quiet, small room) and then repeated in an open environment (a loud, busy hallway). A summary of balance activities for all participants is presented in Appendix 1. A practiced task (walking with a reduced based of support) and a novel task (obstacle crossing with tone discrimination) were examined.

Patient 1 was randomly selected to receive single-task training. This patient took part in the balance activities in Appendix 1 (only balance activities were given). Patient 2 was randomly selected to receive dual-task training under an FP instructional set. She practiced the same set of balance tasks as patient 1 (Appendix 1), while simultaneously performing auditory and visual discrimination tasks as well as cognitive tasks such as subtraction (Appendix 2). She was directed to maintain attention on both postural and secondary tasks at all times.

Patient 3 participated in the same set of activities as patient 2, but under a different instructional set (dual-task training under a VP instructional set). During each session, half of the training was done with a focus on postural task performance, and half had a focus on secondary task performance. During these sessions, data on performance accuracy in the secondary task were recorded: (1) to confirm that the patient really allocated attention to one task or the other and (2) to see the improvement of her performance on this task. For example, during the narrow base walking task while counting backward by threes, number of missteps (errors) were reduced when attention was shifted to the postural task (narrow walking), but increased with a shift in attention to the secondary task (counting backward by threes). Similarly, number of errors on the secondary task depended on whether attention was directed toward the secondary task or the postural task (Appendix 3).

Outcomes

The outcomes of all clinical measures are summarized in Tables 2 and 3. At the end of training, balance had improved in all 3 patients. The BBS score was increased by 3 points for patient 1 (from 52 to 55), by 3 points for patient 2 (from 48 to 51), and by 15 points for patient 3 (from 33 to 48). According to Shumway-Cook et al, "In the range of 56 to 54, each 1-point drop in the BBS scores is associated with a 3% to 4% increase in fall risk. In the range of 54 to 46, a 1-point change in the BBS scores led to a 6% to 8% increase in fall risk. Below the score of 36, fall risk is close to 100%."[41(p817)] Using this model, balance training in our report was associated with improved BBS scores, suggesting a 20% reduction in fall risk for patient 1, a 24% reduction in fall risk for patient 2, and a 45% reduction in fall risk for patient 3.

Patient 1 was able to stand unsupported with feet together independently and stand without losing balance for 1 minute (compared with standing 1 minute with supervision at the first visit). He also was able to place his feet in tandem independently and hold 30 seconds (compared with taking a small step at the first visit).

Patient 2 was able to stand from sitting while not using her hands for support and was able to stabilize independently (compared with using hands for support at the first visit). She was able to sit from standing without losing balance with minimal use of hands (compared with a controlled descent using her hand that she used at the first visit). She also was able to reach forward confidently more than 25.4 cm (10 in) (compared with less than 10 in at the first visit).

Patient 3 was able to stand unsupported with her feet together independently and stand for 1 minute without losing balance (compared with standing with supervision at the first visit), and she could transfer from the chair with arm rests to the chair without arm rests without losing balance and with only minor use of hands (compared with definite need to use her hand on the first visit). She was able to reach forward confidently more than 12.7 cm (5 in) (compared with 5 cm [2 in] at the first visit), to pick up objects from the floor easily and without losing balance (compared with her inability to do the task at the first visit), and to turn to look behind over her left and right shoulders (compared with looking behind one side only at the first visit). She could turn 360 degrees without losing balance in less than 4 seconds each direction (left and right) (compared with turning to one side only at the first visit), to stand independently

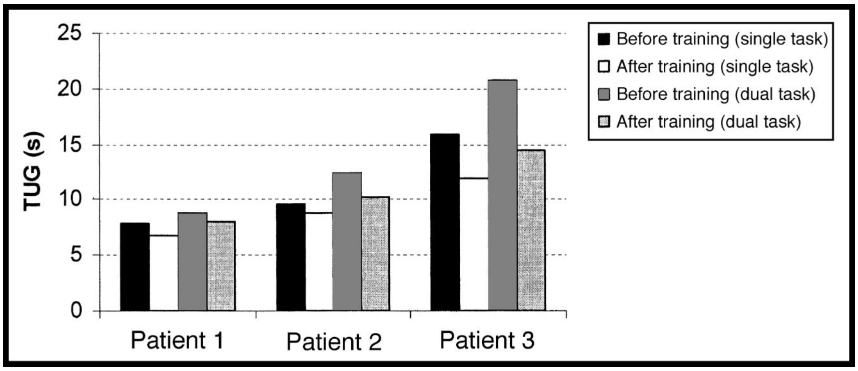

Figure 1.
Timed "Up & Go" (TUG) Test times under single-task and dual-task conditions (in seconds) before and after training. Patient 1 received single-task training, patient 2 received dual-task training with a fixed-priority instructional set, and patient 3 received dual-task training with a variable-priority instructional set.

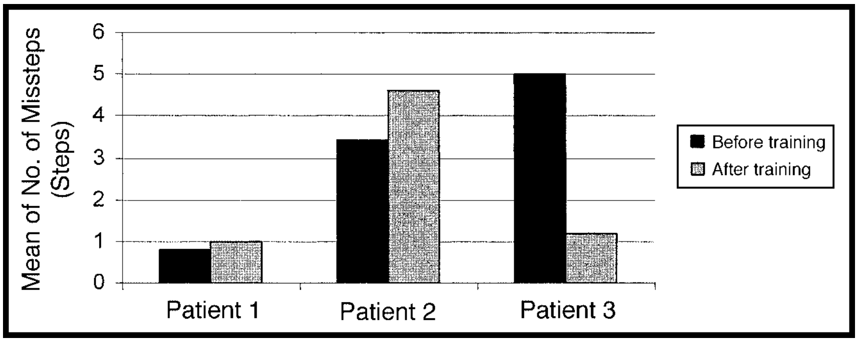

Figure 2.
The mean of number of missteps on novel dual tasks (narrow walking+tone discrimination) before and after training. Patient 1 received single-task training, patient 2 received dual-task training with a fixed-priority instructional set, and patient 3 received dual-task training with a variable-priority instructional set.

and complete 8 steps in more than 20 seconds (compared with completing 4 steps at the first visit), and to place her feet in tandem independently and hold for 30 seconds (compared with placing one foot slightly ahead of the other at the first visit).

The ability to maintain balance during locomotion also improved in patients 2 and 3. Scores on the DGI increased from 21 to 23 for patient 2, and from 18 to 21 for patient 3. Patient 1 scored 24/24 on the DGI at baseline. Patient 2 improved her ability to walk with horizontal and vertical head movements, but she did not improve on the stair task. Patient 3 improved performances on tasks related to changing walking speed and stepping over and around obstacles. Performance on the stairs was unchanged.

All patients completed the TUG tasks faster under both single- and dual-task contexts at the end of the training. However, patients 2 and 3, who received balance training under dual-task conditions, showed more improvement on the TUG under dual-task conditions than under single-task conditions, whereas patient 1 improved more on the TUG under single-task conditions than under dual-task conditions (Fig. 1).

Interestingly, patient 3, who received balance training under dual-task conditions using a VP instructional set, showed improvement on other dual tasks that were not directly trained (novel task). Her mediolateral COM displacement was decreased >2 cm on "obstacle crossing with counting backward by threes" and "obstacle crossing with tone discrimination." The mean number of missteps was also decreased on "narrow walking with tone discrimination" (Fig. 2).

The level of confidence when asked to perform daily activities was increased for all patients. The ABC Scale scores increased from 93% to 97% for patient 1, from 86% to 87% for patient 2, and from 83% to 88% for patient 3. There are no data on measurement error for the ABC Scale, nor information on minimal significant differences in scores.

The TUG under single- and dual-task conditions was repeated at 2 weeks, and the patients demonstrated improvements in balance (decrease in TUG time in both conditions). Patients 1 and 3 demonstrated a substantial improvement (approximately 20%) in both single- and dual-task TUG scores (Tab. 2). Patient 2 showed relatively little improvement in TUG scores under single-task conditions, but she showed a 9.6% improvement in the dual-task condition. A comparison of interim and posttest scores indicated that the patients showed substantial improvement in balance between week 2 and the end of training. For example, the time patient 3 took to finish the TUG under dual-task conditions decreased 17.76% from the first visit to the second week of training, and it decreased 15.19% from the second week of training to the end of 4 weeks of training.

In order to determine retention of training effects, clinical tests were repeated at 3 months after training in patients 1 and 2 (patient 3 was unavailable for the 3-month testing due to her schedule). For patients 1 and 2, improvements on clinical measures of balance were retained at 3 months. In addition, the TUG performance of patient 2 under dual-task conditions had improved by an additional 9% at 3 months, indicating the ability to maintain balance under dual-task contexts also was retained.

Discussion and Conclusions

Balance impairment is a major contributor to falls in adults over 65 years of age,[2,7,8,13,15] and a growing body of evidence has confirmed the importance of cognitive factors to impaired balance among older adults.[19,20,22,25–27,32,33] The application of our report to the development of therapeutic strategies to train this aspect of balance control is just beginning. Efforts to translate research into clinical practice are hampered by the lack of research investigating whether training balance under single-task contexts transfers to dual-task conditions and by the lack of research on the ability to generalize dual-task training to novel task conditions. In addition, information on the relative importance of the instructional set during balance retraining has not been investigated. Certainly work by Kramer and colleagues[39] supports the benefit of dual-task training, albeit on non–balance-related tasks, and the relative importance of instructional set on learning. These results provide the framework for strategies used to train balance in our case report.

In this case report, 3 patients (all older adults with impaired balance) underwent different approaches to training balance, which affected balance control in diverse ways. Following 4 weeks of training, all patients demonstrated improvements in functional balance tasks performed under single-task conditions.

Using the model described by Shumway-Cook et al,[41] balance training in our report was associated with improved BBS scores, suggesting a 20% reduction in fall risk for patient 1, a 24% reduction in fall risk for patient 2, and a 45% reduction in fall risk for patient 3. Patient 3 decreased her TUG time by 4 seconds, scoring below 13.5 seconds, a suggested cutoff point for fall risk in community-dwelling older adults.[33]

Prior to training, all 3 patients had a mediolateral COM displacement during obstacle crossing that was greater than 6 cm, suggesting an increased risk for falling based on data from Chou and colleagues.[48] Following training, patient 1 decreased his mediolateral COM displacement to 4.6 cm during obstacle crossing and now performed at a level consistent with older adults who were healthy and did not have balance impairments.[48]

Improvements in balance under dual-task conditions varied among patients and depended on training type. Patient 1, who received single-task balance training, showed greater improvements in the single-task conditions compared with dual-task conditions, whereas patients 2 and 3, who received balance training under dual-task conditions, demonstrated greater improvements in the dual-task conditions compared with single-task conditions. One possible explanation of this outcome is that task coordination (the strategies that people might use to coordinate dual-task performance) was included in the balance training under dual-task conditions. According to the task coordination and management hypothesis, coordinating and managing multiple tasks is crucial for dual-task performance, and this ability might be reduced in elderly people.[39] These outcomes suggest the conditions under which balance should be trained in older adults. Although balance training under single-task conditions may result in some carryover to dual-task conditions, dual-task balance training appears to be necessary to optimize stability during the performance of concurrent tasks. These outcomes need to be confirmed by research.

The outcomes also suggest the importance of instructional set during balance training. Patient 3, who received balance training under dual-task conditions using a VP instructional set, showed improvement on a novel (untrained) dual task. The outcomes suggest support for the hypothesis of Kramer et al[39] that improvement in novel dual-task performance is the result of the development of improved dual-task processing skills (eg, the ability to allocate attention) and this skill can be generalized to other dual tasks that are not directly trained. This suggests that explicit instructions regarding attentional focus should be included when therapists train balance under dual-task conditions. In this report, during each session, half of the dual-task training was done with attention focused on the balance task, and half of the training was done with attention focused on the secondary task. It is not clear whether this is the optimal way to allocate attentional focus. Again, research is needed to both confirm these outcomes and clarify issues related to instructional set.

This report supports that fact that even a 93-year-old patient could improve her balance performance under dual-task conditions through specific types of training, and the improvement of dual-task processing skills can be generalized to a novel dual task. This outcome is similar to the findings of Fiatarone et al,[52] who demonstrated the benefits of strength training in very frail older residents in a nursing home setting, supporting the concept that age is not a factor in the ability to benefit from training interventions.

There appeared to be improved balance benefits from a training program performed 3 times a week for 4 weeks by the 3 older adults in this case report. Further research is needed to clarify the dose-response nature of this training. Recent research on constraint-induced therapy has shown the importance of high-intensity, short-duration training in improving mobility[53] and balance function[54] in people who have had a stroke. It is not clear whether improved balance could be gained with less training or, alternatively, whether increasing the intensity or duration of training would result in even greater improvements.

This report also showed an inconsistency between self-report (ABC Scale) and performance-based (BBS) measures in patient 3. We believe this discrepancy can be explained because the BBS was performed without the use of an assistive device; in contrast, her reports of confidence in performing activities of daily life were done in the context of using an assistive device. Patient 3 would not answer confidence questions outside the context of using a device, thus the discrepancy between the 2 measures.

One of the limitations in this report is a ceiling effect on performance in patient 1 using both the BBS and the DGI. This reflects a limitation of these tests for detecting change in this patient. In addition, although he perceived that his balance was impaired (this was the stimulus for volunteering in this project), the other measures used in this report did not support his perceptions. It is possible that if we had chosen other clinical measures, we could have documented his imbalance or changed our inclusion criteria to require reduced scores on the selected balance measures.

Finally, the patients' outcomes were sustained at 12 weeks following the end of training in both patients who returned for testing, suggesting the robustness of training over time. The third patient refused follow-up testing. Further research is needed to understand how long training benefits are sustained among older adults and what additional strategies (such as the inclusion of a home exercise program following discharge) are necessary to sustain and maximize benefits.

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Appendix 1.
Balance Activities for All Patients[a]

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12
Stance Activities												
I. Inside Lab												
a. no manipulation		1. Narrow BOS, eyes closed 2. Semi-tandem, eyes open 3. Stepping	1. Semi-tandem, eyes closed 2. Stand on foam, eyes open	1. Stand on foam, eyes open 2. Stand hip abd/add 3. Stepping	1. Stand narrow BOS, eyes closed 2. Semi-tandem, eyes open		1. Step on stool different directions					
b. manipulation							2. Semi-tandem, eyes open with arm alternation			1. Semi-tandem, eyes open, arm alternation 2. Semi-tandem, eyes closed, arm alternation		
II. Outside Lab												
a. no manipulation					3. Step sideways 4. Roll the stick with foot	1. Hip and knee flex/extend 2. Step sideways	3. Draw letters with right foot 4. Draw letters with left foot	1. Stepping exercise 2. Roll ball with foot	1. Hip movement in all directions 2. Roll hip	3. Draw letters with right foot 4. Draw letters with left foot	1. Rock the foot	1. Roll the waist holding a ball 2. Hold a ball and move trunk in different directions
b. manipulation				4. Stand narrow BOS+reach different directions	5. Stand narrow BOS+reach different directions 6. Throw a ball			3. Semi-tandem, eyes open, touch body part	3. Basketball 4. Bowling a ball	5. Perturbed standing holding a ball	2. Reach the hand to touch the opposite knee	
Transitional Activities	1. Sit to stand	4. Sit to stand and walk	3. Sit to stand and pick up objects from the floor	5. Sit to stand and stop varied speed	7. Sit on a ball and perturb	3. Sit to stand on different chair heights	5. Sit to stand and stop, different speeds and holding a basket				3. Sit to stand and walk with head turn varying speed	
Gait Activities												
I. Inside Lab												
a. no manipulation	2. Walk narrow BOS (without cane)	5. Walk narrow BOS 6. Walk sideways 7. Walk around obstacles	4. Walk narrow BOS 5. Walk around obstacles	6. Walk narrow BOS	8. Walk narrow BOS	4. Walk narrow BOS	6. Walk narrow BOS	4. Walk narrow BOS	5. Walk narrow BOS	6. Walk narrow BOS	4. Walk narrow BOS	3. Walk narrow BOS
b. manipulation			6. Walk narrow BOS holding a toy									
II. Outside Lab												
a. no manipulation						5. Walk and kick a ball		5. Walk under different light conditions	6. Walk with a book on the head 7. Walk around the obstacle, cross leg, sideways, and backward		5. Walk up and down stairs	
b. manipulation							7. Walk narrow BOS changing directions (holding a ball)	6. Walk and trunk twist (holding a stick) 7. Walk around obstacle and head turn (holding a ball)		7. Walk narrow BOS, step sideways, backward avoiding obstacles (holding a basket) 8. Walk and kick a ball to hit the cans (holding a ball) 9. Walk and reach and trunk twisting (holding a stick)	6. Sit, semi-tandem, walk, stand on foam, walk sideways, backward avoiding obstacles (holding a basket) 7. Walk and kick a ball to hit the cans (holding a bag) 8. Walk and reach and trunk twisting (holding a basket)	4. Tandem walk, stand on foam, walk sideways, walk backward, stepping, walk backward avoiding obstacles (holding a glass of water) 5. Walk around obstacles (eyes closed) with arm alternation 6. Walk up and down stairs (holding a basket) 7. Walk long step, stepping, walk with high step, pick up object from the floor (holding a basket)

[a] Patients were advanced through this framework on individual basis. BOS=base of support, abd/add=abduction/adduction.

Appendix 2.

Secondary Tasks in Training Programs for Patients 2 and 3

1. **Auditory discrimination tasks:** Patients were asked to identify the noises or voices from a compact disc such as:
   1) Identifying voices (man, woman, child)
   2) Identifying noises (hand clap, door close, dog bark, cat meow)
2. **Name things/words:** Patients were asked to name things such as types of flowers, states, and men's names.
3. **Visual discrimination tasks:** Patients were shown the pictures before and after performing the balance tasks. They were asked to memorize the pictures and to respond if the pictures were the same. They were required to say "yes" if the pictures were the same, and "no" if they were different.
4. **Random digit generation:** Patients were asked to randomly name the numbers between 0 and 300.
5. **Counting backward** (eg, by twos, threes)
6. **Visual spatial task:** Patients were asked to place numbers, objects, or letters in the imagined matrixes. Then, they were required to name the numbers, objects, or letters in the specific matrix cell.
7. **Visual imaginary spatial task:** Patients were asked to imagine and tell the road direction (eg, the road direction from their home to the post office).
8. **N-Back task:** Patients were asked to recite numbers, days, or months backward (eg, December, November, . . . January).
9. **Subtract or add number to letter:** Patients were asked to give the letter as a result of the equation (eg, k−1=j).
10. **Remembering things:** Patients were asked to memorize telephone numbers, prices, objects, or words.
11. **Tell story:** Patients were asked to tell any story such as what they did in the morning, what they did on their vacation, and so on.
12. **Tell opposite direction of action:** Patients were asked to name the opposite direction of their actions. For example, they were required to name "left" when they move their right leg.
13. **Spell the word backward:** Patients were asked to spell a word backward such as "apple," "bird," and "television."
14. **Say any complete sentence:** Patients were asked to say any complete sentence.
15. **Stroop task:** Patients were asked to name the color of the ink while ignoring the meaning of the word.

Appendix 3.

Example of Dual-Task Training (a Variable-Priority Instructional Set) for Patient 3[a]

Balance Activities	Secondary Tasks	Focus (B/S)	Balance (No. of Missteps)		Verbal Response	
			Left	Right	No. of Responses	No. of Errors
Stance Activities						
1. Semi-tandem, eyes open, arm alternation	Spell words forward	80/20				
2. Semi-tandem, eyes closed, arm alternation	Spell words backward	20/80				
3. Draw letter with right foot	Name any words start with letter A–K	20/80				
4. Draw letters with left foot	Name any words start with letter L–X	80/20				
5. Perturbed standing holding a ball	Remember prices (eg, bill payment)	20/80				
6. Perturbed standing holding a ball	Remember prices (eg, groceries)	80/20				
Transitional Activities						
Gait Activities						
7. Walk narrow base of support	Count backward by 3	80/20	0	6	25	0
8. Walk, narrow base of support	Count backward by 3	20/80	7	27	28	0
9. Walk, narrow base of support, step, sideways, backward avoiding the obstacles (holding a basket)	Remember words	80/20				
10. Walk, narrow base of support, step, sideways, backward avoiding the obstacles (holding a basket)	Remember words	20/80				
11. Walk and kick a ball to hit the cans	Tell the opposite direction of a ball	20/80				
12. Walk and kick a ball to hit the cans	Tell the opposite direction of a ball	80/20				
13. Walk and reach and trunk twisting	Visual imaginary task (tell the road direction from home to the lab)	80/20				

[a] Focus (B/S)=focus on balance activities/secondary tasks (80/20=focus on balance activities, 20/80=focus on secondary tasks).

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