

Review Article

# Attention and the control of posture and gait: a review of an emerging area of research

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## Abstract

Research on the relationship between attention and the control of posture and gait is a new and expanding area with studies on young adults revealing the role of cognitive factors in the control of balance during standing and walking. The use of dual task paradigms to examine the effect of age related changes in attentional requirements of balance control and age-related reductions in stability when performing a secondary task has shown that these are important contributors to instability in both healthy and balance-impaired older adults. The attentional demands of balance control vary depending on the complexity of the task and the type of secondary task being performed. New clinical assessment methods incorporating dual-task paradigms are helpful in revealing the effect of disease (e.g. Parkinson's disease) on the ability to allocate attention to postural tasks and appear to be sensitive measures in both predicting fall risk and in documenting recovery of stability. © 2002 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

Postural control has been defined as the control of the body's position in space for the purposes of balance and orientation [1,2]. It has traditionally been considered an automatic or reflex controlled task, suggesting that postural control systems use minimal attentional resources. However, recent research, has provided evidence against this assumption. These studies suggest that there are significant attentional requirements for postural control, and that these requirements vary depending on the postural task, the age of the individual and their balance abilities.

This paper will review some of the research related to four aspects of attention and the control of posture and gait. We will examine (1) research exploring the relationship between attention, posture and gait in young

adults; (2) research investigating the effect of aging on this relationship; (3) research on attention and postural control in balance-impaired fall prone elders; and (4) clinical studies that have begun to apply attention and postural control research to understanding balance and gait problems in specific patient populations. We begin by defining attention and discussing some of the limitations and controversies regarding the dual task paradigm, the primary approach to studying the relationship between attention and postural control.

### 1.1. Defining attention

Attention will be defined here as the information processing capacity of an individual. An assumption regarding this information processing capacity is that it is limited for any individual and that performing any task requires a given portion of capacity. Thus, if two tasks are performed together and they require more than the total capacity, the performance on either or both deteriorates [1–4].

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### 1.2. Methods for studying attention and postural control

Research for studying attention and posture control has used dual task paradigms in which postural control (considered the primary task) and a secondary task were performed together. The extent to which the performance on either task declined indicated the interference between the processes controlling the two tasks, and thus the extent to which the two tasks shared attentional resources [5].

The use of a dual task paradigm to study attention and postural control is not without controversy. Some researchers have stated that using a dual task paradigm to study attentional demands of postural control requires that changes in performance must be limited to the secondary task with no changes occurring in the primary (postural) task [6,7]. Thus results focus on discussing changes in the secondary task, and in this way, attentional demands associated with changes in postural tasks are clearly identified.

In contrast, other authors have examined performance changes in both tasks during a dual task experiment [1,2,8–10]. In these experiments, the dual task design is used both to (1) examine the attentional demands of postural tasks (inferred by changes in the secondary cognitive task); and (2) to examine the effects of performing an attentionally demanding cognitive task on the control of posture. In the latter case, postural control in effect becomes the secondary task, subject to change during the performance of a concurrent task.

It has been suggested that studies showing interacting effects of primary and secondary tasks should not be used to infer attentional demands associated with postural control [11]. It is our belief that these studies are helpful in showing the attentional demands of postural control; however, they are limited in their ability to clarify the exact attentional cost of postural tasks, because of the interacting effects between the two tasks.

### 1.3. Attentional demands and postural control in young adults

Kerr et al. [5] published the first article to demonstrate the attentional demands of stance postural control in young adults. In their experiment, Kerr et al. [5] hypothesized that a difficult balance task would interfere with a spatial (visual) memory but not a verbal memory task, since postural control required visual/spatial processing. Thus, they suggested, there would be visual interference between the postural task and the visual spatial task. They asked 24 young adults to stand with blindfolds on in a tandem Romberg position as their postural task. Changes in postural control were determined by using force platform measures to calcu-

late center of pressure. The visual/spatial cognitive task was the Brooks spatial memory task that involved placing numbers in imagined matrices and then remembering the position of these numbers. The nonspatial verbal memory task involved remembering similar sentences. They found that performing the memory task with the concurrent balance task caused an increase in the number of errors in the spatial but not the nonspatial memory task. The difference in mean number of errors in spatial and nonspatial task in sitting versus when performing the balancing task is shown in Fig. 1. There was no significant difference in postural sway during the performance of either cognitive task. The authors concluded that in young adults, postural control is attentionally demanding; however not all cognitive tasks affect postural control in the same way.

Kerr et al.'s study was the first to show that stance postural control was attentionally demanding in young adults. The next study we review examines whether attentional demands vary as a function of the type of postural task being performed. In this study by Lajoie et al. [12], young adults were asked to perform an auditory reaction time task while sitting, standing with a normal versus reduced base of support and during walking (single vs double support phase). Results from this study indicated that reaction times were fastest for sitting, and slowed for the standing and walking tasks. Reaction times were slower when subjects stood with a narrow base of support compared to a normal base of support. In addition, reaction times were slowest in the single support phase compared to the double support phase of the step cycle.

The authors reported that there was no change in the gait cycle associated with performance of the secondary task. They concluded that postural control is attentionally demanding and demands increase with the complexity of the postural task being performed. The authors noted that a limitation of their study was the use of a simple relatively non-attentionally demanding secondary task. They suggested that use of a more

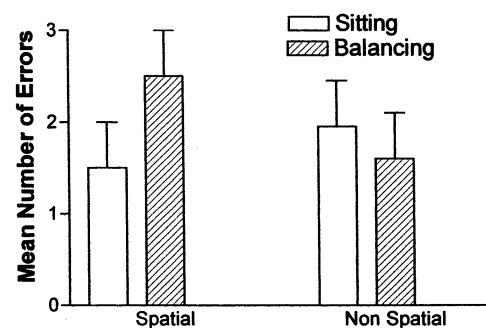


Fig. 1. A comparison of mean number of errors in a spatial versus nonspatial task in young adults in sitting versus when performing the balancing task. From Kerr et al. [5], *J Exp Psychol* 1985. Reprinted with permission.

complex secondary task might have resulted in interference with balance and gait.

Lajoie et al.'s study focused on examining the attentional demands associated gait, reporting no change in gait parameters associated with a secondary task in young adults. In contrast, Ebersbach et al. [6] specifically studied the effect of concurrent tasks on the control of gait. Ten young adults (age 25–42 years) walked on a 10 m conductive walkway that allowed the recording of foot contact during gait. Gait parameters (stride time, double support time) were measured under a single task condition (walking without a concurrent task) and four dual task conditions presented in random order: (1) memory-retention task (digit span recall); (2) fine motor task (opening and closing a coat button continuously during gait); (3) a combination task (digit recall and buttoning task); and (4) finger tapping at 5 Hz or faster. The only dual task condition that produced a significant decrease in stride time (increased stride frequency) was finger tapping. The other gait parameter measured, double support time was significantly affected when the fine motor and memory tasks were performed synchronously with the walking; no other dual task condition affected this parameter. Interestingly, the authors noted that performance of the gait task did affect the digit recall task. The mean digit span recall was 6.7 (range 6–8) during quiet stance, but reduced to 5.8 (range 4–8) during gait. In this study, even the significant changes in gait parameters are fairly small, again suggesting that performance of multiple tasks during a relatively simple task such as unperturbed gait does not present a significant threat to stability in healthy young adults.

One interesting question regarding the attentional requirements of postural control is the time course of attentional demands associated with the recovery of stability. McIlroy et al. [13] hypothesized that the processing requirements of postural control vary during the time course of recovery of stability; therefore the attentional demands would also vary. To test their hypothesis McIlroy and colleagues examined attentional demands continuously during what they refer to as a 'seated balancing task'. Six young adults were tested under three task conditions: seated balancing task, visuomotor tracking task, and a dual task condition involving simultaneous performance of the visuomotor tracking and balance tasks (both perturbed and non perturbed). In the balance task the feet of seated subjects were strapped to a foot pedal that controlled the rotation of an inverted pendulum that was free to rotate about the ankle axis in the sagittal plane. Subjects were required to maintain the upright position of the pendulum. During some of the trials perturbations were given to the pendulum resulting in a forward pendulum rotation. EMG signals from the soleus and tibialis anterior were recorded. The secondary task in

this dual task design was a visuomotor tracking task that required the subjects to track a moving target on a computer screen. The root mean square tracking error was recorded. The results found a disruption in the visuomotor tracking task (as indicated most often by a temporary pause in the tracking) that occurred in 86% of the perturbed trials. The onset of the pause in tracking occurred on average  $325 \pm 93$  ms after the onset of the perturbation. In contrast the balance reaction recorded in the tibialis anterior EMG occurred at an average latency of  $90 \pm 32$  ms. In addition, tracking error was greater during the restoration of the pendulum to an equilibrium position. The authors concluded that in the dual task condition attention was substantially diverted from the visuomotor task when balance was perturbed, presumably redirected to the control of the compensatory response required to restabilize the inverted pendulum. From these results they suggest that balance control involves three distinct phases, each with distinct attentional requirements. The initial phase is automatic with minimal attentional demands; in a second phase, occurring 200–300 ms after the perturbation, there is an attentional shift completely away from the secondary task reflecting attentionally demanding balance control; finally there is a period of divided attention control between both the balance and the secondary task and this persists until equilibrium is restored. This can take up to several seconds.

The idea that attentional demands vary during the time course of recovery of stability is very intriguing. However, it is not clear whether results of this study can generalize to the control of human stance posture. The task of maintaining the equilibrium of an inverted pendulum, which McIlroy and colleagues refer to as a 'balance task' may not pertain to the systems controlling stability in independent stance.

The research does raise the intriguing issue of whether all aspects of postural responses are equally attentionally demanding. It is possible that the initial phase of compensatory responses are more automatic than later portions of the response, hence not as susceptible to the influences of additional cognitive demands. Some support for this comes from Rankin et al. [10] study, discussed in the next section of this paper, which examined early and late changes in the organization of postural muscle activity under dual task conditions in young and healthy older adults.

The next two papers reviewed raise questions regarding the interpretation of results from dual task research on attentional demands on postural control. Maki and McIlroy [14] explored the influence of both attention and arousal on postural control during dual task conditions. Stance postural control (center of pressure-COP) was measured while subjects (39 healthy young adults) performed four different conditions: no secondary task, (2) white noise, (3) listening to a spoken word recording

of a book excerpt, (4) counting backwards silently by 7's. The white noise task was used to increase arousal, while the listen task was intended to divert attention without increasing arousal, and the math task was intended to increase both arousal and attention. Arousal was monitored using measures of skin conductance; in addition subjects' state anxiety was determined using questionnaires. Results showed that the nature of the secondary task had an effect on arousal, with skin conductance being highest on the math task. Task related changes in postural control were limited to those subjects who had higher than average anxiety scores. These subjects leaned further forward during the math task. When skin conduction scores were used as a covariate in the analysis of anterior posterior center of pressure, the dual task effect on postural control during the math task was substantially reduced. The authors conclude that physiological arousal may be a potential confounder when attempting to understand the influence of attention on postural control.

A limitation of this study is that the math task increased arousal in half of the subjects, and this raises questions as to the degree to which this study may be generalized to other dual task studies. In addition, the only change in postural control that was noted was a 2% lean in the forward direction from the vertical position. It is not clear whether this slight shift in posture has any functional significance.

Yardley et al. [15] also question assumptions regarding the role of attentional demands on postural control in dual task research. They investigated the possibility that changes in postural sway seen when subjects performed a spoken task were due to perturbations to posture associated with the task of articulation, rather than due to competing demands for attentional resources. Their subjects included 36 healthy young adults with no history of balance system dysfunction. The postural task involved standing on a force platform; center of pressure was monitored and sway path (total distance in meters traversed by the COP during each 30 s trial) was measured. Twelve subjects were tested on a static forceplate, while 24 subjects were tested on an unstable surface (air filled circular rubber tube, inflated and attached to a piece of board resting on the force plate). Subjects were tested under three visual conditions, no vision, static visual image, and a moving visual image. The secondary tasks used included: counting backwards out loud (attention and articulation), silent counting backwards (attention without demands for articulation), number repetition (articulation alone), and no concurrent task. Subjects were asked to perform the secondary task as accurately and rapidly as possible even when trying to balance. Results showed that the postural tasks did not have an effect on performance of the secondary tasks. The secondary tasks did however affect postural sway. When standing

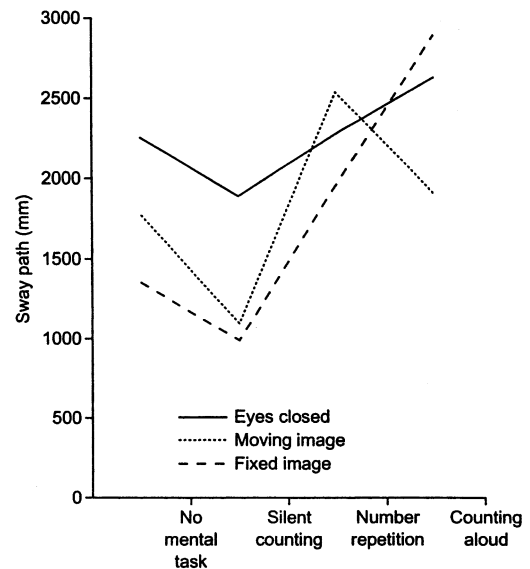


Fig. 2. Effects of visual condition, attentional load and articulation on sway path in young adults when standing on a firm surface. From Yardley et al. [15], *NeuroReport* 1999. Reprinted with permission.

on a stable surface, (shown in Fig. 2), the articulation task significantly increased postural sway; in contrast silent counting had no effect. When standing on an unstable surface, sway was impacted by articulation and visual conditions, but not by attentional load (silent counting). The authors conclude that the increased instability produced by the spoken mental arithmetic task was due primarily to the effects of articulation rather than mental activity. They suggest that the effect of articulation is possibly mediated by respiratory activity involved in speech that directly perturbs posture. However, they note, that instability could also be the result of central interference since speech and balance may share common structures.

The above research suggests that in young adults postural control may be attentionally demanding. These effects however, appear to be small, until the postural system is quite stressed and subjects are required to perform fairly complex secondary tasks. This is an emerging area of research and thus has many unanswered questions. Understanding the role of potential confounders (for example arousal and articulation) to the relationship between attention and postural control is very important.

## 2. Age-related changes in attention and posture control

In contrast to young adults, many researchers have found significant attentional demands associated with postural control in older adults, even under relatively simple conditions. In order to determine the age related changes in the relationship between attention and pos-

tural control, researchers have (1) compared declines in secondary task performance during the simultaneous performance of a postural task in older versus young adults; and (2) examined the effect of increasing cognitive demands on the control of posture [1,2,7,9].

Teasdale et al. [7] examined the extent to which reduction in available sensory inputs increased the attentional demands of postural control in older adults. They asked eight young and nine healthy older adults to perform an auditory reaction time task (press a hand held button as quickly as possible in response to an auditory cue) while standing with feet together on a force plate. They examined reaction time in sitting and standing with feet shoulder width apart as control conditions. Reaction time was then examined under the following sensory conditions: vision, normal surface, no vision, normal surface, vision, foam surface, and no vision, foam surface. Changes in postural control were determined by examining center of pressure (COP) using mean sway range, and percent of time in which the COP spent in a central versus eccentric position. Finally the authors examined the effect of the position of the COP (central vs eccentric position) on performance of the secondary task. Their results found that both young and older adults showed delays in reaction time as the postural task complexity increased (sitting, upright, and standing vision/normal surface). The authors also found that attentional demands increased in both young and older adults when sensory inputs were reduced, even when the COP was in a concentric position. Fig. 3 compares the reaction times in the four sensory conditions in young versus older adults. In addition the reaction time of the older adults was more delayed by the absence of vision during quiet stance than that of the younger adults, indicating that postural control under the no vision conditions required more attentional resources for the older than the young adults. Finally, in contrast to young adults, reaction

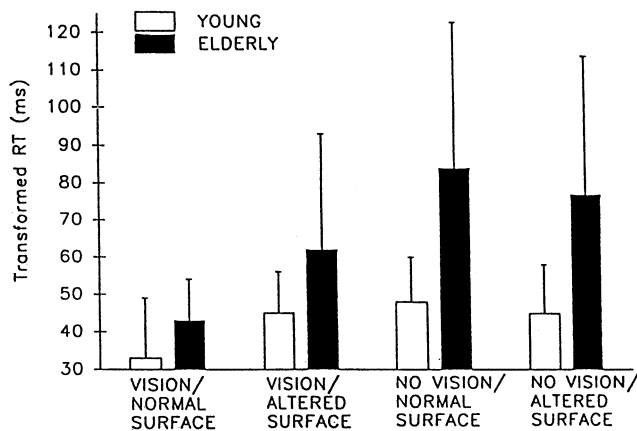


Fig. 3. A comparison of reaction times in young versus elderly subjects standing in four sensory conditions. From Teasdale et al. [7], *Exp Aging Res* 1993. Reprinted with permission.

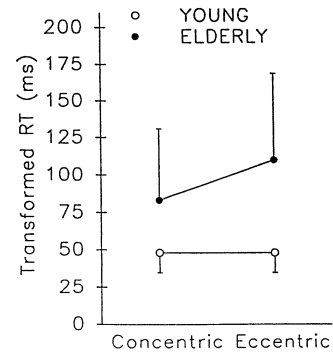


Fig. 4. A comparison of reaction times in young versus elderly subjects when the COP is in a concentric versus eccentric position. From Teasdale et al. [7], *Exp Aging Res* 1993. Reprinted with permission.

times were greatest when the older adult subjects' COP was in an eccentric position. This can be seen in Fig. 4, which compared reaction times in young versus elderly subjects when the COP was in a concentric versus eccentric position. The authors reported that postural sway was not affected by the performance of the auditory reaction time secondary task. They concluded that as sensory information is reduced, the postural task becomes more difficult for older adults and therefore requires more attentional capacity.

Lajoie et al. [16] also investigated age-related differences in attentional demands associated with the control of upright stance and gait. They examined the attentional demands associated with maintenance of a static posture (sitting, standing broad base of support, standing normal base of support) and walking (double support phase vs single support phase) in eight young and eight older adults. They excluded older adults with a history of cerebral vascular accident, head trauma, those who currently used major tranquilizers, tricyclic antidepressants, or barbiturates, and those who were unable to complete the health questionnaire properly. In addition, the older adults had to have no history of falls in the previous 12 months.

While static postural control was not measured, parameters of gait were measured using an instrumented walkway; foot contact was coded to provide temporal values corresponding to the onset and offset of right and left single support, and double support and kinematic analysis was performed using a 3-D system. The secondary task was a simple auditory reaction time task. Results showed a significant group effect and task effect and a group by task interaction. For both young and older adults, reaction times were faster in the sitting task compared to either the standing or walking tasks. A comparison of reaction times in young versus older adults in the five conditions is shown in Fig. 5. There was no effect of the auditory reaction time task on gait parameters in either group.

The authors concluded that, as is true for young adults, in older adults, standing and walking require greater cognitive resources than those required when sitting. In addition, the simple reaction time task did not have a negative effect on the control of stance or gait. The authors suggest that a more complex secondary task would not only have resulted in slower reaction times, but may have compromised the postural stability of the elderly persons.

The deleterious effect of more complex secondary tasks on postural control in young and older adults was shown by Maylor and Wing [8]. They performed an experiment to examine more closely the effects of specific types of secondary tasks on postural sway. Healthy older and young adults stood quietly (primary task) while performing the following types of secondary cognitive tasks intended to test different aspects of the working memory system (involved in information processing, and thus attentionally demanding): (1) a random digit generation task, testing central executive function; (2) Brook's spatial memory task, testing what could be called a visual-spatial sketch-pad (VSSP) function; (3) backward digit recall, testing the phonological loop, which is related to auditory function, and VSSP; (4) silent counting, testing the phonological loop; and (5) counting backwards by threes out loud, testing the phonological store of the phonological loop.

They found that younger adults performed significantly better than older adults on all the cognitive tasks except silent counting, and were more stable than the older adults across all tasks. They found that age-related differences in postural stability were significantly increased when performing two of the five cognitive tasks, the Brooks' spatial memory task (2) and the backward digit recall task (3). Based on previous re-

search, Maylor and Wing suggested that backward digit recall also used the visual spatial sketch-pad function. Thus they concluded that age-related differences in balance were increased by cognitive tasks involving the visual spatial sketch-pad part of working memory. Maylor and Wing proposed that these reductions in balance control under conditions 2 and 3 could be due to an increased reliance on vision for postural control by older adults as a result of proprioceptive and/or vestibular loss [8].

In the next studies reviewed, researchers have asked whether increasing the difficulty of the postural task by challenging the motor system would lead to deterioration in performance of older compared to young adults. In an initial study in 1990, Stelmach et al. [17] asked whether recovery of quiet stance stability after performing a voluntary arm swing task would be delayed in older adults ( $N = 8$ ; mean age = 70.0 years), compared to young adults ( $N = 8$ ; mean age = 20.0 years), when performing one of two secondary tasks. The first task was a bimanual hand squeeze task (they squeezed a force transducer), and the second was a mathematical task (verifying the number of correct answers in a series of additions). The authors measured the effect of these work loads on mean velocity, range, and variability of range of center of foot pressure during the destabilizing activity of arm swinging and a following recovery period. They found that, following seven seconds of 1 Hz arm-swinging activity, older but not young adults showed a marked increase in recovery time to normal quiet stance when concurrently performing the math task; however performance of the squeeze task did not impair postural recovery. They concluded that there is increased interference between postural recovery and secondary tasks in older compared to young adults, when the secondary tasks require substantial cognitive processing. This research also suggested that there may be a hierarchy in secondary task demands, with a simple manual motor task requiring fewer attentional resources, and thus less interference with postural control, than a more complex math task.

The above experiments examined attentional constraints on the balance performance of older adults in response to a voluntary movement, arm swinging, but it would also be important to know if recovery from externally produced balance threats requires more attention for the older adult than the young, since it is in these situations that most older adults fall. To answer this question Brown et al. [18] performed experiments in which 12 older and 14 younger subjects were asked to respond to a series of unexpected platform displacements that were of increasing velocity, either with no secondary task or while performing a math task (count backward by threes). Subjects were instructed to avoid stepping as possible. At lower platform displacement velocities subjects used a feet-in-place strategy to re-

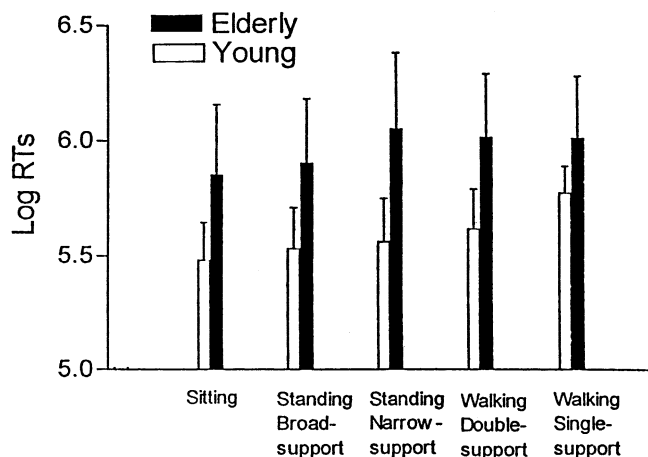


Fig. 5. A comparison of reaction times for sitting, standing broad-support, and standing narrow-support tasks and during walking in the double versus single support phases in young versus elderly subjects. From Lajoie et al. [16], *Exp Aging Res*, 1996. Reprinted with permission.

cover stability, while at higher velocities, subjects typically used a step to recover stability. The effect of the counting task was assessed by comparing kinematic variables related to feet-in-place and stepping recovery strategies.

Reaction times on the math task were slowed when performing the postural recovery task, indicating that recovery of stance stability was attentionally demanding in both age groups. In addition, attentional demands varied depending on the type of postural movement strategy used to recover stability. Compensatory stepping was associated with slower reaction times for the math task than an in-place recovery strategy. The authors suggest that motor strategies used for postural recovery are associated with a hierarchy of attentional demands. Use of a feet-in-place movement strategy during recovery of stability was associated with the lowest attentional demands; in contrast compensatory stepping was associated with the greater attentional demands.

Also reported in this study was the effect of a secondary task on postural control. Results showed that although counting backwards did not affect the type of postural recovery strategy used, it did affect the kinematics of stepping. For both age groups, steps occurred when the center of mass was located in a more central location within the base of support when the secondary task was added and this effect was greatest in the older adults. The authors hypothesize that this relationship between attentional demands and stepping in older adults may contribute to instability and falls. In a dual task condition, older adults tend to step sooner than young adults. Since stepping is a more attentionally demanding strategy for older adults than young adults, in a dual task context, the use of a stepping strategy may in fact promote postural instability and falls if insufficient attentional resources are allocated to ensure a safe step.

In an effort to understand why older adults step sooner under dual task conditions, Rankin et al. [10] determined if interference between the cognitive and postural tasks affects the organization of neuromuscular responses used in balance recovery in a subset of subjects involved in Brown et al.'s research. Rankin compared muscle response characteristics in response to platform perturbations under single versus dual task (subtracting by threes) conditions. Surface EMG's were used to characterize muscle activity in gastrocnemius (response to forward sway) and anterior tibialis. Muscle onset latencies and amplitudes (integrated EMGs) of the postural muscles of the ankles were compared between the dual (math & balance) and single task (balance only) conditions.

The authors found that for both groups of subjects, onset latency of postural muscle responses did not change under dual task conditions. In contrast, the

### Percent Differences in IEMG Activity of the GA Between the No Math and Math Conditions (350-500 ms)

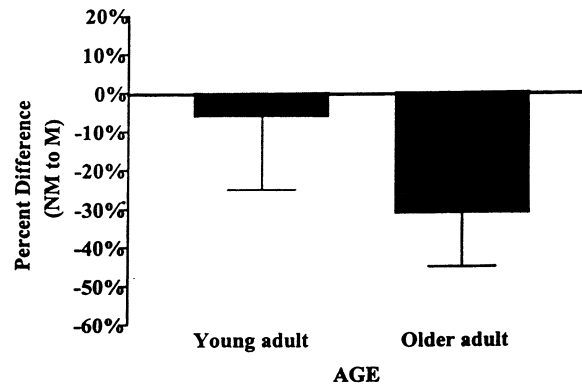


Fig. 6. A comparison of the percent difference in EMG amplitude for young versus older adults when recovering balance in the math (balance plus secondary task) versus no-math (balance only) conditions. From Rankin et al. [10], *J Gerontol*, 2000. Reprinted with permission.

amplitude of postural muscle activity was significantly reduced during performance of a secondary task, with older adults showing a significantly greater reduction than young adults. Fig. 6 shows the percent difference in EMG amplitude for the young versus older adults when recovering balance in the math (balance plus secondary task) versus no-math (balance only) conditions. In this figure, older adults show a much larger reduction in response amplitudes compared to young adults. The authors conclude that the additional attentional processing requirements during the performance of multiple tasks resulted in a decline of postural muscle activity (reduced amplitude) during recovery of balance. They suggest that the reduction in EMG amplitude under dual task conditions in older adults may contribute to early stepping observed in these subjects. The authors hypothesize that deficient muscle recruitment, as seen by reduced EMG activity, results in the selection of an alternate response strategy, the stepping strategy, in order to ensure successful recovery of stability. It should be noted that the reduction in response amplitude was not immediate, but started 150–350 ms after plate onset. These results thus support those of McIlroy et al. [13], above, showing varying attentional requirements for different phases of postural recovery.

Many falls in older adults occur during gait as a result of tripping or slipping. While studies by Lajoie and colleagues reviewed earlier did not demonstrate an effect of a simple secondary task on non-perturbed gait, Chen et al. [19] examined the effect of dividing atten-

tion on the ability of young versus older adults to step over obstacles. In this study young and healthy older adults were asked to walk down a walkway and to step over a virtual object (a band of light) when a red light turned on at the end of the walkway. (Fig. 7 illustrates the experimental set up for this study). On some trials they were asked to perform a secondary task involving giving a vocal response. The authors measured obstacle contact in single versus dual task conditions in young versus older adults. Results indicated that obstacle contact was increased when attention was divided in young and older adults; however it was significantly higher in the older compared to young adults. The authors concluded that diminished abilities to respond to physical hazards in the environment when attention is directed to a second task might contribute to high rates of falls in the elderly.

In summary the research reviewed on attention and postural control in healthy older adults demonstrates, (1) that postural control appears to be more attentionally demanding in older adults compared to young; and (2) performance of a secondary task that is attentionally demanding appears to have a more deleterious effect on postural control in older adults compared to young. It is not clear whether problems in older adults are the result of: (1) an inability to shift attention between the two tasks; (2) a reduction in attentional

capacity; (3) an increased demand for limited attentional resources associated with impairments in the postural control system; or (4) some combination of these factors.

### 3. Contributions of attentional factors to balance impairments in older adults

Historically, age-related deterioration in balance abilities has been attributed to decreases in sensory or motor system function. However, parallel research in the area of cognition suggests that there may be other intrinsic sources of instability, including attentional allocation deficits. The focus of recent research studies is whether the age-related reductions in stability in many older adults are increased significantly with added cognitive demands. For example, research suggests that many falls in balance-impaired older adults occur not when they are simply walking, but when they are walking and simultaneously performing a secondary task (such as talking or manipulating an object) [33]. It has thus been hypothesized that these falls are not due to balance deficits in isolation, but to the inability to effectively allocate attention to balance in multi-task conditions [1,2,12]. Thus a number of studies have been performed to explore the effects of performing a secondary task on postural control in balance impaired older adults.

Shumway-Cook et al. [9] extended the work of Teasdale and colleagues to the examination of the attentional demands of postural control in 20 young, 20 healthy and 20 balance-impaired older adults (age > 65 years), under both normal (normal support surface) and reduced sensory conditions (altered support surface: foam). Balance-impaired subjects had a history of two or more falls in the previous 6 months, and scored significantly poorer than did the healthy older adults on three clinical measures of balance. Two secondary cognitive tasks, sentence completion, a language processing task [20], and judgement of line orientation (JOLO) a visual spatial processing task [21], were used to produce changes in attention during the performance of a concurrent postural task. In the JOLO task the subject was presented with an array of lines numbered 1–11 set at different orientations. Above the array are two unnumbered lines set at the same orientation as two of the numbered array. Subjects were required to pick the two numbers that correctly identify the orientation of lines. In the Sentence Completion task the subject was presented with four blanks, some of which had a letter preceding them. The subject was required to create a four word sentence by replacing each blank with a word. It was hypothesized that the greatest interference to postural control would be when the JOLO task was performed, since both tasks require visual processing

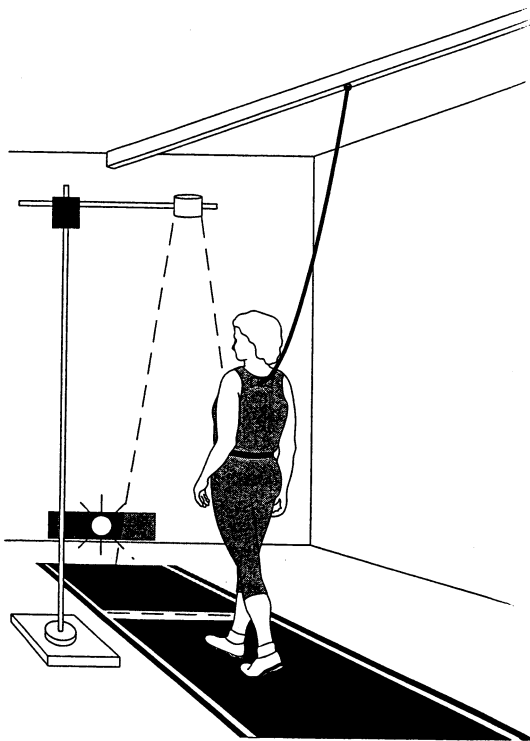


Fig. 7. The experimental set up used by Chen et al. to examine the effects of divided attention on stepping over obstacles in young versus older adults. From Chen et al. [19], *J Gerontol* 1996. Reprinted with permission.



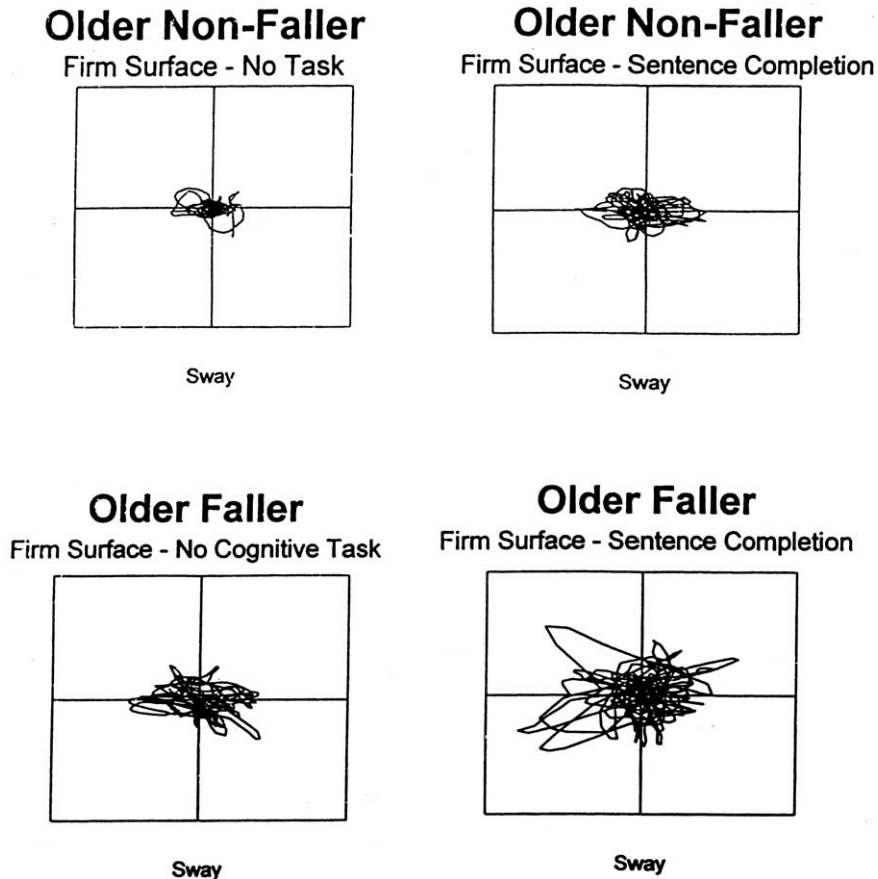


Fig. 8. Comparison of displacement of the COP during a no task versus sentence completion task in an older adult with no history of falls and an older adult with imbalance and a history of falls. From Shumway-Cook et al. [9], *J Gerontol*, 1997. Reprinted with permission.

pathways. Stance postural control was evaluated using center of pressure measures (distance traveled in mm for each 30-s trial).

Results showed that during the simultaneous performance of cognitive and postural tasks, decrements in performance occurred in the postural stability measures rather than the cognitive measures, for all three groups. The more challenging postural task, standing on a foam surface, did not affect either the number of, or the accuracy of responses on either of the secondary cognitive tasks. Instead, the primary interference was the effect of the secondary task on the postural task. For both young and healthy older adults, the JOLO task did not significantly increase the distance traveled by the COP; however the sentence completion task did. In contrast, both tasks significantly affected postural stability (increased COP) in the balance impaired older adults. Fig. 8 shows sway path of a healthy older adult (non-faller) and a balance impaired older adult (faller) when performing the postural task alone versus when performing the postural and sentence completion task simultaneously. Note the marked increase in sway of the balance impaired older adult when performing the secondary task.

In a second study Shumway-Cook and Woollacott [1,2] expanded the sensory contexts used to examine the effect of different types of sensory environments on postural stability during the concurrent performance of attentionally demanding cognitive tasks. Subjects included 18 young adults (age < 45), and 36 older adults (age > 64). The older adult group included 18 healthy older adults and 18 with a history of imbalance and two or more falls in the previous 6 months. A choice reaction time auditory task was used to produce changes in attention while subjects stood quietly under three different visual conditions and two different surface conditions. Visual conditions included normal vision (eyes open), no vision (eyes closed) and visual motion. A single axis optokinetic stimulator was used to present visual motion cues in the environment. The optokinetic stimulator used an electric motor to project moving vertical line stimuli on a screen that surrounded the subject on three sides and was approximately 24" from the subject. The two surface conditions included a firm non-moving surface (firm surface), and a sway referenced surface. In the sway referencing, the surface rotated about the axis of the ankle joint in direct proportion to body sway. Sway referencing the plat-

form surface was used to reduce the availability of somatosensory inputs related to sway. Thus the six sensory conditions included (1) firm surface, eyes open; (2) firm surface; eyes closed; (3) firm surface, visual motion; (4) sway referenced moving surface, eyes open; (5) sway referenced moving surface, eyes closed; and (6) sway referenced moving surface, visual motion. A series of auditory tones were presented continuously during the 20 s trials. Subjects were asked to maintain stability and respond as quickly as they could, indicating whether they had heard a high versus low tone. Postural stability was quantified using force plate measures of center-of-force (total sway path in mm). In addition, “falls” were recorded. A “fall” was defined as either a step or a loss of balance in which the subject was caught by the protective harness.

Results showed that in young adults, the addition of an auditory tone task did not significantly affect postural sway in any of the six sensory conditions. In the healthy older adults, the addition of a secondary task affected postural sway only in the two most difficult sensory conditions, 5 and 6, when both visual and somatosensory cues for postural control were disrupted. In contrast, to the young and healthy older adults, in the balance-impaired older adults, the addition of the secondary task significantly affected postural stability in all sensory conditions. These results are shown in Fig. 9. The authors also reported that in the three most difficult sensory conditions (4) sway referenced moving surface, eyes open, (5) sway referenced moving surface, eyes closed, (6) sway referenced moving surface, visual motion normal, several of the older adults who had been able to maintain stability in the single task context, were unable to maintain balance in the dual task condition. These subjects either stepped or were caught

by the protective harness. The authors proposed that in order to perform multiple tasks safely, some older adults might be limited to a restricted set of environmental conditions, in which sensory conditions are optimal.

This study suggests support for the concept that attentional demands associated with postural control are highest in balance impaired older adults. Thus this subset of older adults may be at significantly higher risks for falls when performing multiple tasks, one of which is maintaining stability.

Bauer et al. [22] compared recovery of subjects from platform perturbations in single and dual task conditions in order to determine if balance-impaired older adults have greater difficulty recovering stability when distracted compared to healthy older adults. Postural recovery from a platform perturbation was investigated in 15 young adults, 15 healthy elders and 13 balance impaired older adults. A vocal auditory reaction time task was used as a secondary task. To determine the effect of the cognitive task on postural recovery, kinetic, kinematic and neuromuscular measures of a compensatory step response were investigated. Attentional demand of the postural response was assessed by the reaction time of the simultaneous cognitive task.

Results showed that balance recovery using a feet-in-place strategy was more attentionally demanding in balance-impaired older adults than in healthy older adults. This was shown by longer reaction times for the secondary cognitive task for the balance-impaired compared to the healthy older adults. In addition, the balance-impaired older adults took longer to stabilize their center of pressure and regain stability in the dual-task compared to the single task condition. In contrast, the healthy older adults showed no change

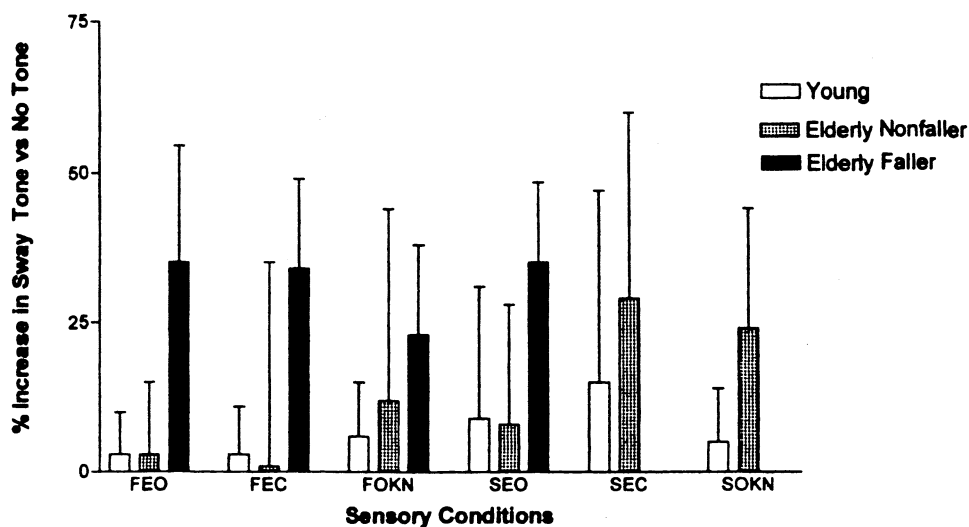


Fig. 9. A comparison of percentage increase in sway in the tone versus no-tone condition as a function of sensory context in young versus older adults [fallers versus non fallers (see text for explanation of sensory conditions)]. From Shumway-Cook and Woollacott [1,2], *J Gerontol*, 2000a, b. Reprinted with permission.

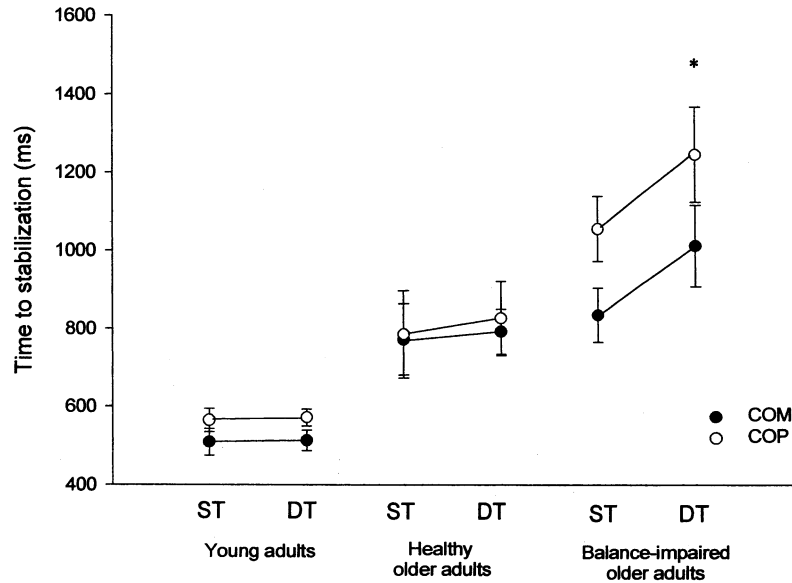


Fig. 10. A comparison of the time taken to stabilize center of pressure and regain stability following a platform perturbation in single versus dual task conditions in young, healthy older and balance impaired older adults. From Brauer et al. [22], *J Gerontol*, in press. Reprinted with permission.

between conditions. These results are shown in Fig. 10. The authors suggest that because balance impaired older adults take longer to establish a stable position when performing a second task, they have a higher risk for falls than healthy elderly under dual task conditions.

Results from these studies on age related changes in attentional demands of postural control suggest that the effect of a secondary task on postural control depends on many factors including the complexity of the secondary task, the difficulty of the postural task, and the age and balance abilities of the subject. Researchers are now beginning to apply this research paradigm to clinical problems, including understanding motor control problems in patient populations such as those with Parkinson's disease (PD), as well as to the development of assessment and treatment methods related to balance and gait.

#### 4. Clinical research related to attention and postural control

Several studies have used a dual task paradigm to study the effects of a concurrent task on gait in individuals with PD [23–25]. Camicioli et al. [23] examined the effects of a simultaneous verbal fluency task on gait in individuals with PD with and without freezing of gait. Freezing in gait is defined as an unexpected and uncontrollable sudden halting during gait, and is a problem for many persons with PD because it impairs mobility, causes falls, and is poorly controlled by medication. The mechanisms underlying freezing in gait are not

known. Freezing is often exacerbated by distracting cues such as walking through doorways, thus raising the possibility that attentional processes are involved in modulating freezing [23].

In this study 19 patients with PD [ten with freezing (PD-F) and nine without freezing (PD-NF)] participated, as did 19 sex and age matched healthy control subjects. Gait was measured while subjects walked 15' in one direction, turned and return to the starting point at a self-selected pace. The number of steps and the time in seconds to walk the total 30 feet was recorded. If patients froze while walking, this time was included in total walking time. The secondary task involved audibly reciting as many male names as possible while performing the gait task. The results indicated that the number of steps and time taken to walk 30' was significantly different among the three groups. PD-F patients took significantly more steps (mean change:  $4.2 \pm 4.6$  steps) and were slower (mean change:  $2.0 \pm 1.4$  s) than either the PD-NF ( $0.11 \pm 1.62$  steps,  $0.44 \pm 1.51$  s) or the control groups ( $1.53 \pm 1.54$  steps,  $1.53 \pm 2.04$  s). While the PD-NF group took more steps than the control group, they were not significantly slower. Two PD-F patients froze during single task gait trials, and one while in the dual task condition.

Interestingly the authors note that Antiparkinsonian medication improved gait parameters in the PD-F patients to the level of the PD-NF patients, but did not influence the dual task effect. They suggest that PD-F patients are more dependent on attention when walking than PD-NF patients or control subjects. The authors conclude that PD patients with freezing may have additional frontal attention deficits that interfere with

compensation during simultaneous task performance. These frontal deficits may form the basis for freezing of gait in PD.

Bond and Morris [25] investigated the effects of a motor task (with two levels of difficulty) on gait in 12 subjects with PD and 12 healthy controls matched for age, sex, and height. Subjects performed a 10-m gait task while walking: (1) freely; (2) while carrying a tray; and (3) while carrying a tray with four plastic glasses on it. Gait measurements included: gait speed, stride length, cadence and the proportion of walking cycle spent in double limb support. For all subjects with PD, experiments were performed 1 h after the last dose of medication. Results found that PD patients were significantly slower in the single versus walking with tray and glasses condition (but not tray alone), while there was no effect of either dual task on gait speed in the control group. In addition, there was a significant reduction in stride length from free walking to walking with tray and glasses in the PD but not the control group. Finally there was no effect of dual task on cadence or double support in either group.

The authors conclude that gait in subjects with moderately severe PD is relatively unaffected by concurrent performance of a relatively simple second task; however is markedly affected by performance of more complex attentionally demanding tasks. They go on to suggest that subjects with PD have an overreliance on cortically mediated attentional mechanisms when executing movements because of defective basal ganglia function.

Camicioli et al. [26] examined the effects of distraction on gait in healthy elderly subjects and patients with Alzheimer's disease (AD). Using the same methods as those used in their study with patients who had PD, they examined the effects of a vocal fluency task (repeating male and female names) on the time and number of steps taken to walk 30'. Their subjects included 23 healthy 'young-old' subjects (mean age  $72 \pm 3.6$  years), 20 'old-old' (mean age  $86 \pm 4.4$ ) and 15 subjects with AD who did not have Parkinsonism (mean age  $74 \pm 13$ ). The concurrent performance of a second task significantly increased the time taken to walk 30' in subjects with AD compared to the two groups of healthy older adults, but not the number of steps taken. The authors suggest their results support Nutt et al.'s proposal that walking is dependent on higher cortical inputs [34]. As a result, mental tasks interfere with normal ambulation in the elderly, and cause a disproportionate slowing in AD patients.

These studies show the disproportionate effect of concurrent tasks on stability during gait in adults with specific types of neural pathology. Results are helping health care practitioners to understand some of the mechanisms underlying motor control problems in patient populations. The potentially deleterious effects of attentionally demanding tasks on the control of posture

and gait in many populations including balance impaired elders and person's with specific neurological pathology, has underscored the importance of developing clinical measures that evaluate posture and gait under both single and dual task conditions.

Lundin-Olsson et al. [27] examined whether decrements in stability under dual task conditions is predictive of falls in older adults. They examined the validity of the "stop walking when talking test" to predict falls in older adults. They tested 58 residents living in sheltered accommodations and followed them for 6 months to determine fall rates. Twelve residents stopped walking while talking, and ten of them fell during the 6 month follow-up period. They reported the positive predictive value of "stops walking when talking" was 83% (10/12), and the negative predictive value was 76% (35/46). The specificity of the test was high (95%); however the sensitivity was low (48%). The authors concluded that the 'stops walking when talking' test is a simple, fast test that requires no equipment. The limitation of this study is that it limits the measurement of effect of a secondary task to complete cessation of walking. This means that older adults, who continue walking but are highly unstable when talking, would not be recognized as having failed the test.

In order to increase the sensitivity of a measure to detect a decrease in mobility under dual task conditions, a different clinical test was selected and modified. Lundin-Olsson et al. [28] modified the timed up and go (TUG) test to add a manual task, carrying a glass of water, in order to investigate the effect of a second task on balance, mobility and falls in older adults residing in an institutional setting. The timed up and go test (TUG test) requires a subject to stand up, walk 10 feet, turn, walk back, and sit down. Time taken to complete the test is strongly correlated to level of functional mobility [29]. Lundin-Olsson et al. found that residents who had a time difference of  $> 4.5$  s between the TUG<sub>manual</sub> and the TUG were more prone to falls during the following 6 months. They concluded that the difference in time taken to perform the TUG and TUG<sub>manual</sub> is useful for identifying institutionalized elderly who are prone to falls.

Shumway-Cook et al. [30] examined the sensitivity and specificity of the TUG under single and dual task conditions in identifying fall-prone community dwelling older adults. Because previous research has shown that different types of secondary tasks have varying effects on posture and gait, the effects of two types of tasks were investigated, a cognitive versus manual task. Thirty older adults (mean age  $78 \pm 6$  years, range 65–85), half with balance impairments and a history of two falls in the previous 6 months, participated. The study measured the time taken to complete the TUG under three conditions [TUG, TUG with a subtraction task (TUG<sub>cognitive</sub>), and TUG while carrying a full cup of

water (TUG<sub>manual</sub>)]. Results showed that both the cognitive and the manual task significantly increased the time taken to complete the TUG in both groups of older adults, with the greatest effect in the balance-impaired older adults. The three measures, TUG, TUG<sub>manual</sub> and TUG<sub>cognitive</sub>, were equivalent with respect to identifying older adults prone to falls. The authors concluded that the TUG alone is a sensitive and specific predictor of falls in community dwelling older adults. They noted that determining the effect of a secondary task on the TUG test is still a useful method for identifying the older adult at risk for losing balance when simultaneously performing multiple tasks.

Thus researchers have begun to investigate the usefulness of dual task methods in evaluating balance and gait, and in predicting future falls. Researchers have also begun to examine the relationship between attentional demands and the control of posture and gait during recovery of function and the rehabilitation process.

A clinical question of importance to rehabilitation is the extent to which the use of an assistive device increases attentional demands associated with gait. In order to answer this question Wright and Kemp [31] examined the use of a rolling walker, a standard pick-up walker and no walker on voice response time during a secondary task, in healthy young adults. They found that voice response time was significantly slower when walkers were used, with a standard pick-up walker requiring significantly more attention than the rolling walker. The results of this research serve as a reminder to clinicians that, while walkers may aid in stabilizing fall-prone patients, they also require considerable attention for use. Thus, patients may need practice in allocating attention primarily to their walking task, or advice to refrain from performing other tasks at the same time.

Finally, Guertz et al. [32] examined changes in attentional demands associated with the recovery of postural control following injury. They used a dual task paradigm to examine the attentional demands associated with recovery of postural control in subjects with lower limb amputation. They hypothesized that the recovery of postural control following injury is characterized by increasing automaticity, and this would be reflected by improved performance under dual task conditions indicating decreasing attentional demands associated with postural control. They studied the effect of a concurrent attention-demanding task on upright stance at the start and at the end of the rehabilitation process. A modified Stroop test was used as the secondary task. Balance performance was expressed as the root mean square value of the COP velocities in the AP and lateral direction. Eight persons with unilateral lower limb amputation, who received their first prosthe-

sis and were involved in a rehabilitation program, participated. A group of healthy age-matched controls also was tested.

For the single task condition, subjects stood for 15 s on a forceplate while balance (COP) was measured. For the remaining 15 s, subjects performed the Stroop test, and balance (COP) was measured under dual task conditions. (Three subjects in the amputation group who could not perceive colors performed a subtraction task instead of the Stroop test. Speed of response (number of colors or numbers given) during the 15 s trial was used as a measure of performance on the second task. In addition, functional recovery related to ADL and ambulation was measured during the course of rehabilitation. Results found that, compared to the healthy control group, persons with amputation swayed more in all directions (greater COP). Balance control in the single task condition did not change following rehabilitation; however there was a significant improvement in balance control in the dual task condition.

The authors concluded that an important characteristic of the central reorganization process after a lower limb amputation is a decreasing need for attentional resources related to postural control. They further suggested that a dual task procedure is an effective way to estimate the level of automaticity of a postural task. A limitation of this study is the lack of information regarding changes in performance on the secondary task associated with changes in postural control.

## 5. Summary

In summary, research examining the relationship between attention and the control of posture and gait is a relatively new, but rapidly expanding area. Studies involving young adults are increasing our understanding of the role of cognitive factors in the control of stability during activities such as standing and walking. Studies using dual task paradigms to examine the effect of age related changes in attentional requirements of balance control and age-related reductions in stability when performing a secondary task, suggest that these are important contributions to instability in both healthy and balance impaired older adults. For both healthy and balance-impaired older adults, attentional demands associated with postural control vary, depending on the complexity of the task and the type of second task being performed. Finally, clinical applications of attention and postural control research are improving our understanding of motor control problems in patients with specific types of pathology, such as PD. New clinical tools incorporating dual-task paradigms into assessment methods are helpful in predicting falls and appear to be sensitive measures in documenting recovery of postural control.

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