Attentional Dynamics in Postural Control During Perturbations in Young and Older Adults

Mark S. Redfern,[1,2] Martijn L.T.M. Müller,[2,5] J. Richard Jennings,[3,4] and Joseph M. Furman[1,2]

Departments of [1]Bioengineering, [2]Otolaryngology, [3]Psychology, and [4]Psychiatry, University of Pittsburgh, Pennsylvania. [5]Department of Psychology, University of Amsterdam, The Netherlands.

Temporal dynamics of attention during postural perturbations in young and older adults were investigated. Nineteen young and older subjects performed simple reaction time tasks during translational platform perturbations. Auditory or visual stimuli were presented randomly at delays from the onset of the platform perturbation. Reaction time was slowed before and during the platform movement, particularly in older subjects. Reaction times to stimuli presented at a 250-millisecond delay or later were not influenced by perturbation. The reaction times to the auditory stimuli were influenced more by perturbation than were those to visual targets. The postural response was unaltered by the presence of the reaction time task, but it differed between groups. Attention is engaged in response to a perturbation during the preperturbation time and during the initiation of the postural response in young and older adults. Sensory selection occurs in young and older adults, but to a greater degree in older subjects.

SEVERAL recent studies have investigated the role of attention in postural control by using the dual-task paradigm, examining the interference between a cognitive task and a balance task. Different cognitive tasks have been used in combination with standing and walking, including mental arithmetic (1,2), visuospatial tasks (see, e.g., 3), reaction time tasks (see, e.g., 4 and 5), and word recall (see, e.g., 6). As challenge is varied in one task, the amount of interference created in the other task is thought to reflect the degree of attention required to perform the task. The studies, taken together, have shown minimal interference between cognitive tasks and postural control during quiet standing on a fixed support surface; however, as postural challenge increases, increasing attentional processing appears to be required.

Normal aging appears to result in increased attentional requirements for balance during standing (1–3,5,7–12). Recently, other studies have found attentional influences on locomotion as well, particularly in older subjects (6,13–16). This consistent aging effect may be part of a more general phenomenon of "age-associated permeation of behavior with cognition" (6). Thus, age-related changes in sensory and motor function appear to increase the requirement for cognitive regulation of sensorimotor processes. However, it is still unclear exactly how attention is being used in postural control, and what specific actions are most influenced by aging.

Only recently have studies begun to address attentional allocation during postural tasks involving reactions to postural perturbations (2,17–19). Two similar studies by Brown and collegues (2) and by Rankin and colleagues (19) examined the attentional demands on recovery from a horizontal anterior platform translation during a cognitive task (counting task) in healthy young and older subjects. The counting task was initiated before the perturbation and continued throughout the perturbations. Brown and colleagues (2) found an increase in counting time immediately after perturbation in young and older subjects, suggesting that there was some competition for attention during the recovery process from the perturbation. Minimal effects of the cognitive task on the postural strategy types used (ankle, hip, and stepping) were found. However, within postural strategies, the cognitive task did influence posture in the older subjects. These results suggest that attentional requirements vary with sensorimotor requirements within a particular response. Brauer and colleagues (18) also examined postural recovery with a dual task and found that a postural response to a perturbation required attention in healthy older subjects and young subjects similarly, whereas balance-impaired elderly subjects showed greater attentional requirements. Although these studies indicate that attention is utilized during postural perturbations, the dynamics of this process could not be determined because of the lack of temporal resolution in the cognitive task and because the cognitive task was always engaged prior to the perturbation response.

The aim of this present study was to investigate the temporal dynamics of attention during postural recovery in older and young adults by using a dual-task paradigm with reaction time tasks as the information-processing component. Portions of these data have been presented in abstract form (20,21).

METHODS

Subjects

Nineteen healthy young adults, 11 women and 8 men, mean age 23.5 (*SD* 3.2) years, and 19 healthy older adults,

9 women and 10 men, mean age 78.8 (*SD* 3.4) years (range 73–85 years), with no history of vestibular or neurological disorders, participated in this study. All subjects were screened for normal vestibular function through caloric and rotational testing (22) and completed a neurological examination (by J. Furman) prior to enrollment. Other inclusionary criteria for the subjects were normal scores on functional abilities tests performed by a physical therapist, including a score of greater than 21 on the Physical Performance Test (23), a timed up-and-go score of less than 26 s (24), and a Sickness Impact Profile score of less than 6 (25). Hearing tests were performed to test for normal thresholds, including pure tone thresholds greater than the 90th percentile (at 1, 2, 4, 6, and 8 kHz) based on data from Robinson and Sutton (26). Older subjects were also given the Mini-Mental State Examination (27) and were required to have a score of greater than 23 to be included in the study.

Informed consent was obtained prior to any participation. This study was approved by the Institutional Review Board of the University of Pittsburgh.

Instrumentation

The instrumentation consisted of a posture platform (Equitest, Neurocom, Inc., Clackamas, OR) that provided translational perturbations of the floor. The platform movements were translations of 0.64 and 3.17 cm, with durations of 150 and 250 milliseconds, respectively. A harness was used to prevent falling. The harness did not inhibit movement during the perturbation. For the reaction time (RT) task, subjects pushed a handheld microswitch button in response to either a visual stimulus (green light emitting diode in front of the subject at eye level) or an auditory stimulus (1000-Hz tone). The 1000-Hz tone was presented for 1 second at 60 dB through headphones. The timing of the movement of the platform and the presentation of the RT stimulus was controlled by a computer. RT data were collected from the button push. Postural data were collected from force plates. All data were digitally recorded at a sampling rate of 1000 Hz.

Procedure

The independent variables in this study were perturbation size, perturbation direction, time interval between the perturbation onset and the RT stimulus, and the sensory modality of the RT stimulus. The two perturbation sizes used were 0.64 and 3.17 cm, and they were blocked. The perturbation direction (forward or backward) was randomly chosen during the trials. The time intervals (δ) between the RT stimulus and platform movement initiation were -100, 0, 100, 250, 500, 750, and 1000 milliseconds. For $\delta = -100$ milliseconds, the RT stimulus occurred prior to platform movement. At $\delta = 0$ milliseconds, the stimulus and platform movement initiation occurred simultaneously. For positive δ, the RT stimulus occurred after platform movement began. Platform movement was completed within 250 milliseconds; therefore, stimuli at $\delta = 100$ milliseconds occurred during the floor movement and $\delta \geq 250$ milliseconds occurred after floor movement. The RT tasks were simple RT responses to two sensory modalities: auditory or visual. The sensory modality was also blocked so that only visual or auditory stimuli were presented within each block.

One practice session was given on a separate day before data collection began. The practice session included both visual and auditory RT tasks while the subjects were seated. The subjects then stood on the posture platform during perturbations to become acquainted with the platform translation. Finally, the subjects practiced performing the RT tasks during perturbations at $\delta = 0$ milliseconds. Thus, subjects were fully acquainted with the protocol, including the magnitude of the perturbations and the combination of perturbations and RT tasks. Subjects were told to respond as fast as possible to the RT stimulus while maintaining balance. Each subject was required to correctly respond to the stimulus in greater than 90% of the practice trials to continue to the data collection phase.

During data collection trials, the experimental protocol was administered over three sessions, each on separate days. Data collection trials consisted of four blocks of 57 RTs: 48 experimental trials and 9 catch trials. Of these 9 catch trials, 6 were postural catch trials, in which a postural perturbation occurred but no RT stimulus was presented. The other three trials were RT catch trials without a perturbation, but with a RT event. These catch trials were included to prevent predictability and increase alertness. The blocks were as follows: 0.64-cm perturbation with visual RT task, 0.64-cm perturbation with auditory RT task, 3.17-cm perturbation with visual task, and 3.17-cm perturbation with auditory task. Presentation of the four blocks was randomized within days. Within each block, the delay times between the onset of perturbation and the RT stimulus were randomly varied among the seven chosen delays (δ). The inter-stimulus time was randomly selected to be between 2 and 4 seconds. Three minutes of seated rest was provided between trials to reduce fatigue.

Data Analysis

The dependent variables were RTs and latency of the postural response to the perturbation. The RTs were computed as the difference between the onset of the stimulus (auditory or visual) and the activation of the button. The latency of postural response was estimated by using center of pressure (COP) recordings. The COP time series were analyzed to find temporal and magnitude characteristics of the response, including the initial latency of response (T_L), the time from initial active response to the maximum COP response (T_1), and the amplitude of the response ($A_{max} - A_1$). Figure 1 illustrates how these values were computed for a representative COP trace. The latencies were determined by finding the first maximum of the second derivative of the COP signal after platform movement. The first change in acceleration response after that point was marked T_L; T_1 was marked as the first relative maximum of the COP response after onset of the active response. Both T_L and T_1 were plotted and visually checked for correctness.

Statistical analyses were performed by using repeated measures analysis of variance with subjects nested within age groups. A significance level of $\alpha = .05$ was used throughout the analyses. Logarithmic transformations were performed prior to analysis to normalize the distributions of the RTs. Post hoc comparisons were made for significant multiple-level variables.
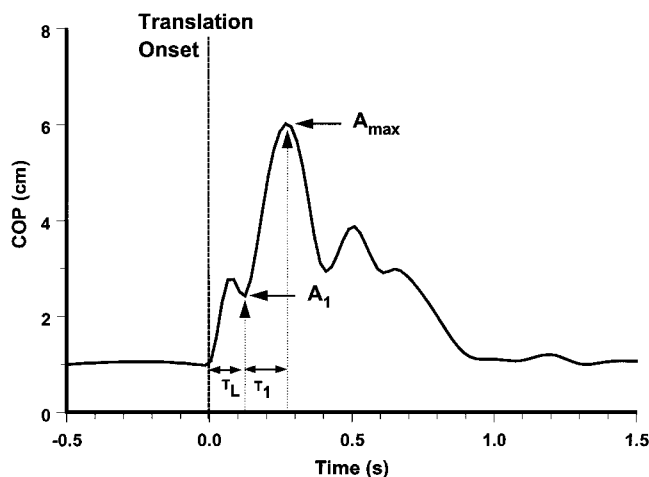
Figure 1. Center of pressure (COP) response to platform translation for an older subject. The COP trace was parameterized as follows: initial latency of response (T_L), time from initial response to maximum COP response (T_1), amplitude at initial response (A_1), and maximum amplitude of response (A_{max}).

RESULTS

Reaction Times

RT was influenced by main effects of age ($F = 28.0$; $p < .001$), δ ($F = 98.4$; $p < .001$), stimulus modality ($F = 109.7$; $p < .001$), and perturbation size ($F = 72.0$; $p < .001$). Perturbation direction did not influence the RTs. The interactions that significantly affected RT were Age $\times$ Size ($F = 20.3$; $p < .001$), $\delta \times$ Modality ($F = 26.7$; $p < .001$), $\delta \times$ Size ($F = 10.9$; $p < .001$), and Age $\times \delta \times$ Size ($F = 5.1$; $p < .001$). As expected, overall, the older subjects had longer RTs compared with the young, and RTs were longer for the visual stimulus compared with the auditory (Figure 2). Age also modulated the influence of the time delay (δ) between perturbation and stimulus on the RT measure, that
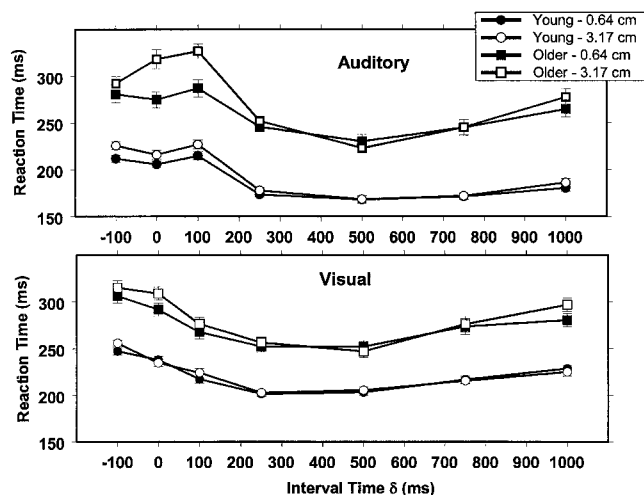

Figure 2. Reaction times (RTs) as a function of delay, and perturbation size for young and older subjects. The top panel shows RTs for the auditory task; the bottom panel shows RTs for the visual task. Error bars are *SE*.
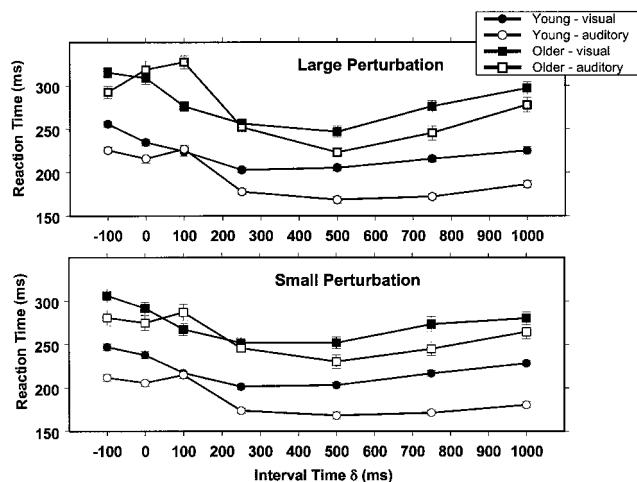

Figure 3. Reaction times (RTs) previously presented in Figure 2 are rearranged to show the responses to the two sensory modalities on the same plot for young and older subjects. Note that the auditory RTs at $\delta = 100$ milliseconds increase whereas the visual RTs decrease; this was true for both large and small perturbations. For the young subjects, auditory RTs at $\delta = 100$ milliseconds are actually greater than visual RTs.

is, the three-way interaction. The RTs were greater before the perturbation occurred ($\delta = -100$ milliseconds) compared with those after the perturbation was completed (250 milliseconds and beyond; $p < .001$). Perturbation size had an effect on the RT for $\delta = 0$ and 100 milliseconds ($p < .01$), and this size effect was larger for the older subjects than for the younger subjects ($p < .001$).

The significant interaction of δ and stimulus modality indicated that the RTs for visual stimulus were affected by the delay time differently than the RTs for the auditory stimulus. This effect was greatest during the postural perturbation. For $\delta = 100$ milliseconds, auditory RT *increased* and visual RT *decreased* compared with RT values at $\delta = 0$ milliseconds in both the young and older subjects (Figure 3). The auditory RTs at $\delta = 100$ milliseconds were actually greater than the visual RTs.

Postural Responses

A repeated measures analysis of variance was performed for the variables associated with the postural response to the perturbation estimated from the COP time series (T_L, T_1, and $A_{max} - A_1$). Each variable was investigated independently, with all primary independent variables (age, perturbation size, direction, RT modality, and δ) and first- and second-order interactions included in the model. The results of this analysis showed no effect of delay time (δ) or any interaction of δ with the other independent variables on any of the postural variables. Thus, we refuted our hypothesis that the activation of postural response would be delayed during a concurrent RT task compared with after the RT task was completed. There was also a Size $\times$ Direction interaction effect on T_L ($F = 4.38$; $p = .037$), with the larger perturbation initiating a longer latency than the small perturbation for the backward direction. There was no perturbation size effect for forward perturbations.

Age of the participants altered the latency and amplitude of the COP response. The latency to response (T_L) was shorter in the older adults compared with the young ($F = 8.76$; $p = .005$) (Figure 4). The time from the initial active response to the peak of the COP response (T_1) was affected by age ($F = 33.0$; $p < .001$), direction ($F = 10.0$; $p = .002$), and the interaction of Age $\times$ Size ($F = 22.6$; $p < .001$). Older subjects had faster T_1 responses, particularly for the smaller perturbations (Figure 4b). Directional effects showed faster T_1 responses for backward perturbations compared with forward perturbations in both young and older subjects. The magnitude of active COP response ($A_{max} - A_1$) was affected by age ($F = 6.81$; $p = .01$), size ($F = 787$; $p < .001$), Age $\times$ Size ($F = 37.5$; $p < .001$), Size $\times$ Direction ($F = 13.1$; $p < .001$), and Age $\times$ Size $\times$ Direction ($F = 28.5$; $p < .001$). Older subjects had a greater response than young subjects for both perturbation sizes, with a greater increase in response during the large perturbation. Backward perturbations elicited greater responses compared with forward perturbations, especially for the older subjects.

DISCUSSION

We found that age modulated the interference between a postural recovery to a perturbation and a simple RT task. Performance of a RT task was influenced by perturbation size before and during the perturbation, particularly in older subjects. The perturbation size did not affect RT at or beyond 250 milliseconds after initiation of platform movement. The postural response to the perturbation was sensitive to age and perturbation size, but it was not influenced by the presence of a concurrent RT task. Larger perturbations had a more significant impact on attention to the concurrent RT task in older relative to younger adults.

The influence of the postural perturbation on RT for delay times shorter than 250 milliseconds suggests that there is a shift of attention while a response to a perturbation is made. In addition, the size of the perturbation appears to influence the level of attention to the perturbation response, with increasing attention for the perturbation with increased size. The interference of the postural task on RT dissipated by 250 milliseconds after the perturbation. These results suggest that there is a rapid attentional dynamic during postural recovery. In the preparation and execution of the postural response, attention is focused on identifying the sensory cues associated with the perturbation and to executing the appropriate postural motor response. Once the postural response has been executed, an attentional shift away from the postural task to the RT task occurs. Because perturbation size was presented in blocks, subjects could gauge in advance the proper response magnitude to the perturbation. However, direction of the perturbation was randomly presented within blocks of trials. This resulted in a choice between two motor programs: one for a forward perturbation and one for a backward perturbation. The process of determining the proper motor program and executing that program appeared to require attention within 250 milliseconds of the initial perturbation.

Young and older subjects seem to have the same temporal attentional dynamic, because both groups showed no perturbation size effect on RT for delays of 250 millisec-
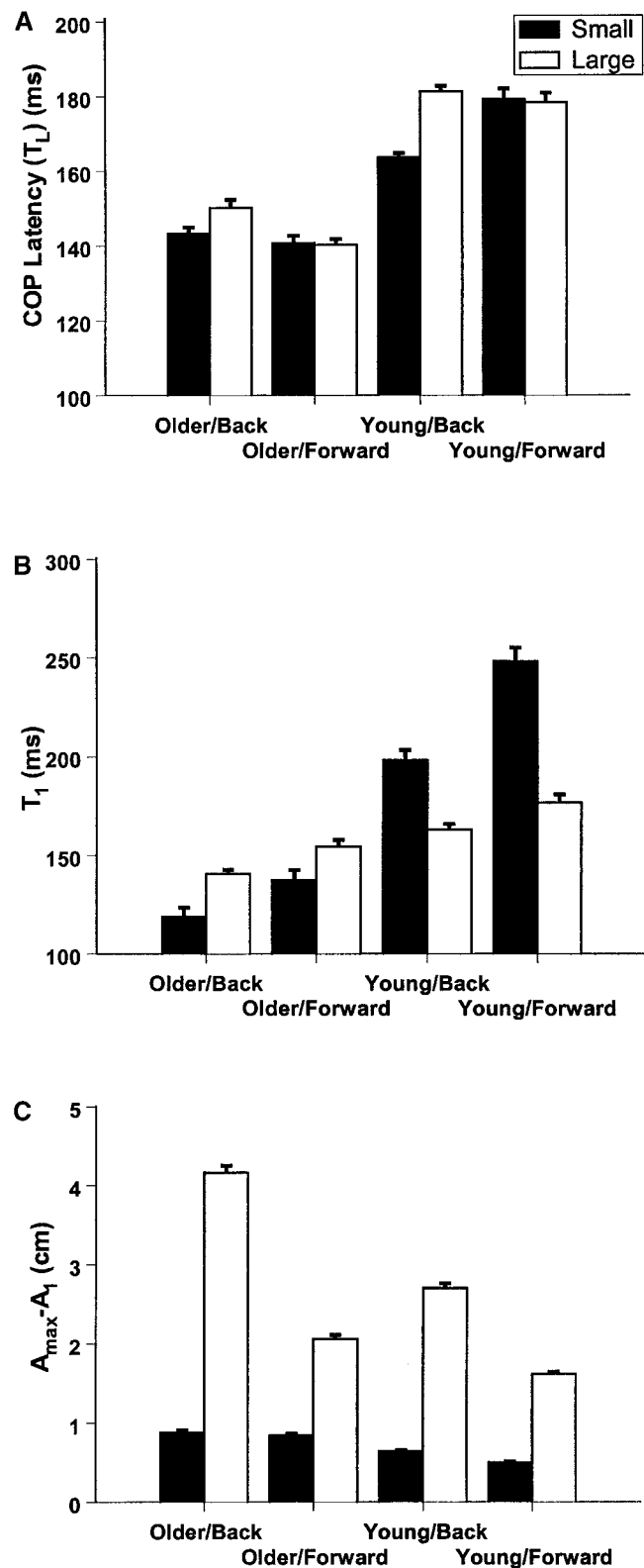

Figure 4. Postural response measures for small (0.64 cm) and larger (3.17 cm) perturbations: **A**, latency of center of pressure (COP) response (T_L); **B**, time from first active COP response to the maximum COP (T_1); **C**, magnitude of the COP response ($A_{max} - A_1$). Error bars are *SE*.

onds and beyond. Aging does appear to alter the degree of attention to the perturbation during preparation and execution of the response. Older subjects appear to have increased attention to the execution of postural response; however, the temporal dynamics of that response are rapid in both age groups.

The attentional dynamics during the postural response were affected by the stimulus modality of the RT task. The auditory RT task appeared to suffer from increased interference more than the visual RT task. This influence emerged in the preperturbation responses ($\delta = -100$ milliseconds) and was marginally stronger among older participants. Perturbation size had a greater effect on auditory RT compared with visual RT. This sensory modality effect is contrary to our original hypothesis that there would be greater interference in visual RT response during the perturbation because the visual system is used in postural control. Instead, a facilitation of visual RT responses occurred. This may be due to specific attentional influences on sensory selection, with a reduction of auditory attention, a facilitation of visual attention, or both. This modulation of attention could serve to facilitate vision because visual information is used in the postural control response whereas audition is not. Concurrent with a visual facilitation, a "filtering" of auditory sensation could also occur because this sensory information is not believed to be primary in postural control during a perturbation. This apparent sensory selection persisted through the 100-millisecond delay; the auditory RT response was significantly slowed compared with the visual RT. The stimulus presented at $\delta = 100$ milliseconds occurred during the platform movement, but before the COP response was initiated. Thus, there is greater potential for interference at this time. This sensory modality effect is consistent with the argument that sensory facilitation or filtering may be occurring.

The performance of the RT task did not alter the postural response in either young or older subjects, suggesting that attention to the postural task was primary in this dual-task perturbation paradigm. The motor responses for these postural tasks were invariant to the delay times between the RT stimulus and perturbation, again suggesting that postural control is primary. This result is consistent with the findings of Rankin and colleagues (19), who showed that electromyographic onset latencies of the postural muscles during perturbations did not vary under dual-task conditions of mental arithmetic. Brauer and colleagues (18) also found no effect of a dual task on postural response to a perturbation in healthy older adults when the postural task was primary. However, the primacy of postural recovery seen in the present study and by Rankin and colleagues (19) and by Brauer and colleagues (18) may not generalize to all situations. Some standing postural studies have shown an interference of information-processing tasks on sway (8,28), particularly in older adults (5,12). Thus, cross interference of information-processing tasks on balance has been demonstrated. This same interference could possibly take place in a perturbation response under the right conditions. For example, postural conditions that have a low probability of a perturbation may not have the same primacy of attention, particularly if they are coupled with an engaging and complex information-processing task. These conditions would probably be more representative of an unexpected slip or loss of balance that occurs in activities of daily living that may show an attentional effect on perturbation responses. In addition, the results of Brauer and colleagues (18) indicate that postural response to a perturbation is altered by a cognitive dual task in balance-impaired elderly subjects, even when the postural task is primary. Thus, the impact of attention on postural recovery to a perturbation is probably context specific and dependent on the health of the postural control system as well.

Compared with young subjects, older subjects had faster postural responses to perturbations. The COP latencies were shorter and the magnitudes of the COP response were larger for the older subjects. This may reflect an increased focus of attention on the upcoming perturbation in the older subjects. Although the postural task appeared to be primary in both groups, the older subjects may have placed a greater priority on the postural response. This is an interesting observation given that older individuals are typically slower rather than faster while performing tasks. The size of the perturbations may have been a factor. Older subjects may perceive more risk from these small perturbations than young subjects. If larger, more challenging perturbations would be used, similar responses between the two populations may occur. Clearly, further work will be necessary to separate attentional effects from aging effects on COP adjustments.

The rapid shift of attention found in this experiment differs from the recent perturbation study of Maki and colleagues (17). They used a continuous visual tracking task as the cognitive task and used the time at which tracking failed after the perturbation as an indication of when attention switched to the postural task. They found that tracking was paused or deviated at 480 milliseconds (*SD* 187) after the perturbation. This latency was after the initial postural response that occurred at around 144 milliseconds. Their interpretation of this result was that the initial postural response, termed the "automatic postural response," was indeed automatic and did not require a shift of attentional processes; rather, attention was involved in later postural adjustments. The delay between the postural perturbation and the change in the tracking task found by Maki and colleagues (17) may not accurately reflect when the attentional shift occurred because of the anticipatory motor programming typical in such tracking tasks. That is, a feed-forward or predictive component presented in the tracking task may have delayed the appearance of a tracking error despite interference between underlying attentional processes during the perturbation response. The differences between these two experiments must be further explored to determine if the attentional dynamics are influential in the initial response, as suggested in this study, or if there is indeed an initial "automatic" component that does not require attention. The differential influence of age on recovery and the automatic components of the posture response will then become of central interest.

Address correspondence to Mark S. Redfern, PhD, 128 EEI Building, 200 Lothrop Street, Pittsburgh, PA 15213. E-mail: mredfern@pitt.edu

REFERENCES

1. Stelmach GE, Zelaznik HN, and Lowe D. The influence of aging and attentional demands on recovery from postural instability. *Clin Exp Aging.* 1990;2:155–161.
2. Brown L, Shumway-Cook A, Woollacott M. Attentional demands and postural recovery: the effects of aging. *J Gerontol Med Sci.* 1999;54A: M165–M171.
3. Kerr B, Condon SM, McDonald LA. Cognitive spatial processing and the regulation of posture. *J Exp Psych Hum Perform Percept.* 1985;11: 617–622.
4. Teasdale N, Simoneau M. Attentional demands for postural control: the effects of aging and sensory reintegration. *Gait Posture.* 2001;14: 203–210.
5. Redfern MS, Jennings JR, Martin C, Furman JM. Attention influences sensory integration for postural control in older adults. *Gait Posture.* 2001;14:211–217.
6. Lindenberger U, Marsiske M, Baltes PB. Memorizing while walking: increase in dual-task costs from young adulthood to old age. *Psychol Aging.* 2000;15:417–436.
7. Stelmach GE, Teasdale N, DiFabio RP, Phillips J. Age related decline in postural control mechanisms. *Int J Aging Hum Dev.* 1989;29:205– 223.
8. Maylor EA, Wing AM. Age differences in postural stability are increased by additional cognitive demands. *J Gerontol Psychol Sci.* 1996;51B:P143–P154.
9. Shumway-Cook A, Woollacott MH, Baldwin M, Kerns K. The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *J Gerontol Med Sci.* 1997;52A:M232– M240.
10. Teasdale N, Bard C, Dadouchi F, Fleury M, LaRue J, Stelmach GE. Posture and elderly persons: evidence for deficits in the central integrative mechanisms. In: Stelmach GE, Requin J, eds. *Tutorials in Motor Behavior.* Vol. 12. Amsterdam: North-Holland; 1992:917–931.
11. Teasdale N, Bard C, LaRue J, Fleury M. On the cognitive penetrability of postural control. *Exp Brain Res.* 1993;19:1–13.
12. Teasdale N, Stelmach GE, Breunig A. Postural sway characteristics of the elderly under normal and altered visual and support surface conditions. *J Gerontol Biol Sci.* 1991;46:B238–B244.
13. Chen HC, Schultz AB, Ashton-Miller JA, Giordani B, Alexander NB, Guire KE. Stepping over obstacles: dividing attention impairs performance on old more than young adults. *J Gerontol Med Sci.* 1996;51A: M116–M122.
14. Lajoie Y, Teasdale N, Bard C, Fleury M. Upright standing and gait: are there changes in attentional requirements related to normal aging? *Exp Aging Res.* 1996;22:185–198.
15. Lajoie Y, Barbeau H, Hamelin M. Attentional requirements of walking in spinal cord injured patients compared to normal subjects. *Spinal Cord.* 1999;37:245–250.
16. Mulder T, Berndt H, Pauwels J, Nienhuis B. Sensorimotor adaptability in the elderly and the disabled. In: Stelmach GE, Homberg V, eds. *Sensorimotor Impairment in the Elderly.* Dordrecht, The Netherlands: Kluwer; 1993:413–426.
17. Maki BE, Norrie RG, Zecevic A, et al. Initiation and execution of rapid postural reactions and stepping movements: which phases require visuospatial attention? In: Duysens J, Smits-Engelsman B, Kingma H, eds. *Control of Posture and Gait.* Maastricht, The Netherlands: ISPG; 2001:573–576.
18. Brauer SG, Woollacott M, Shumway-Cook A. The interacting effects of cognitive demand and recovery on postural stability in balance-impaired elderly persons. *J Gerontol Med Sci.* 2001;56A:M489–M496.
19. Rankin J, Woollacott M, Shumway-Cook A, Brown L. Cognitive influence on postural stability: a neuromuscular analysis in young and older adults. *J Gerontol Med Sci.* 2000;55A:M112–M119.
20. Redfern MS, Müller LTM, Jennings JR, Furman JM. Attentional dynamics in older adults during perturbations. In: Duysens J, Smits-Engelsman B, Kingma H, eds. *Control of Posture and Gait.* Maastricht, The Netherlands: ISPG; 2001:598–601.
21. Müller LTM, Redfern MS, Jennings JR, Furman JM. Temporal dynamics of postural control during a cognitive task. In: Duysens J, Smits-Engelsman B, Kingma H, eds. *Control of Posture and Gait.* Maastrich, The Netherlands: ISPG; 2001:581–584.
22. Furman JM, Cass SP. Laboratory testing. In: Baloh RW, Halmagyi M, eds. *Electronystagmography and Rotational Testing. Disorders of the Vestibular System.* New York: Oxford University Press; 1996:191– 210.
23. Ruben DB, Sui AL. An objective measure of physical function in elderly outpatients. *J Am Geriatr Soc.* 1990;38:1105–1112.
24. Podsialdo D, Richardson S. The timed "up & go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc.* 1991;39: 142–148.
25. Schuling J, Greidanus J, Meyboom-De Jong B. Measuring functional status of stroke patients with the Sickness Impact Profile. *Disabil Rehab.* 1993;15:19–23.
26. Robinson DW, Sutton GJ. *A Comparative Analysis of Data on the Relation of Pure-Tone Audiometric Thresholds to Age.* Middlesex, United Kingdom: National Physical Laboratory; 1978. Acoustics Report Ac 84.
27. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of the patient for the clinician. *Psychiatr Res.* 1975;12:189–198.
28. Shumway-Cook A, Woollacott MH. Attentional demands and postural control: the effect of sensory context. *J Gerontol Med Sci.* 2000;55A: M10–M16.