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Attentional Demands and Postural Recovery: The Effects of Aging

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Background. Cognitive demands associated with balance and locomotion may contribute to the incidence of falling among older adults. This study addressed issues related to the effects of aging on the attentional demands of recovering from an external disturbance to balance. This research also investigated whether performing a secondary cognitive task differentially affects postural recovery in young versus older adults.

Method. Fifteen young and 10 healthy older adults were exposed to a series of balance disturbances. Attentional demands were assessed using a dual task paradigm where postural recovery served as the primary task, and counting backwards served as a concurrent secondary cognitive task. The effect of the counting task was assessed by comparing kinematic variables related to feet-in-place and stepping recovery strategies.

Results. Recovering upright stance was found to be attentionally demanding in both age groups. The type of recovery strategy did not influence attentional demands in young adults; however, a hierarchy of increasing attentional demands between the ankle strategy and compensatory stepping was apparent among older adults. In addition, stepping appears to be more attentionally demanding for older adults than for younger adults. Counting backwards did not affect the type of strategy used; however, 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.

Conclusions. The ability to recover a stable posture following an external perturbation is more attentionally demanding for older adults than for younger adults. This would suggest that for some older adults, an increased risk for loss of balance and falls may result if sufficient attentional resources are not allocated to the task of postural recovery.

RECENT research using a dual task paradigm suggests that the sensorimotor processing essential to postural control requires attentional resources. Several researchers have documented that even highly practiced postural tasks require some cognitive processing, and that the degree of processing varies with the complexity of the postural task and the age of the subject. For example, it has been shown that dynamic equilibrium tasks such as walking appear to require more attention than do static equilibrium tasks such as sitting or standing quietly (1–5). One unanswered question is whether one of the most common and most difficult balance tasks, that of recovering stability after an unexpected threat to balance, requires attentional resources. Therefore, the first goal of the study was to examine whether recovery of stability following an unexpected perturbation is attentionally demanding.

Previous research has described a continuum of three movement strategies (ankle, hip, and step) that are used to recover stability in response to perturbations of increasing amplitude and velocity (6,7). However, the attentional requirements associated with these stereotypical strategies of balance recovery have not been studied. Therefore, one purpose of this study was to examine the attentional demands of three movement strategies that are used to recover stability. We hypothesized that the continuum of postural strategies is associated with a continuum of attentional demands. In this hierarchy, we hypothesize that recovery strategies typically used in response to small amplitude/low velocity disturbances (i.e., ankle strategies) will have the lowest attentional demands, and recovery strategies typically used in response to high amplitude/fast velocity disturbances (i.e., compensatory stepping) will have the highest attentional demands.

Previous dual task research has shown that, in certain contexts, postural stability can be affected by the performance of an additional cognitive task (8,9). For example, Chen and colleagues (8) have shown that when walking, the risk of contacting an obstacle increases when attention is divided. Shumway-Cook and coworkers (9) have shown that simultaneous performance of a cognitive task during quiet stance resulted in an increase in postural sway. It is not known whether the performance of a cognitive task will affect the ability to recover from an unexpected threat to balance. Thus, a second purpose of this study was to examine the effect of performing an attentionally demanding cognitive task on postural recovery, specifically on the kinematic variables related to control of the whole body center of mass (COM). We predicted that, in a dual task condition, selective commitment of attention to a cognitive task would result in significant changes in COM position and time to peak displacement. We expected that these effects would lead to a change in the type of movement strategy used to recover stability in response to an external perturbation.

Studies have shown that decreased balance control, either due to injury or aging, increases the attentional requirements associated with maintaining stability (2,4,9,10). Lajoie and colleagues (2) have demonstrated that there is an age-related difference in the attentional demands of upright stance. Shumway-Cook et al. (9) have shown that during quiet stance, differences in postural sway between young and older adults are more apparent in a dual task condition. It is not known how aging affects the attentional demands of strategies used to recover postural stability. Nor is it known how aging affects the influence of a secondary task on postural recovery. Therefore, a third purpose of this study was to examine the effect of age on the relationship between attentional demands and postural recovery.

Methods

Subjects

Twenty-five healthy adults volunteered to participate in this study. Of these, 10 were older adults (n = 7 males, n = 3 females) and 15 were younger adults (n = 5 males, n = 10 females). The age of the older participants ranged between 68 and 89 years (M = 78.74, SD = 4.98 years); the younger participants ranged in age from 21 to 36 years (M = 25.34, SD = 5.22 years). All participants were free from cardiovascular disorders, diabetes mellitus, or any known cognitive or neurological disorders. The older participants were required to receive medical clearance to participate in this study, and all subjects were informed of the testing procedures before signing a consent form. The subjects were tested without shoes or socks but, when applicable, were permitted to wear their glasses during testing.

Protocol

Subjects were asked to perform a backward digit recall task prior to, and while recovering from, an external disturbance to balance. The balance disturbance, or perturbation, was delivered using a moving forceplate apparatus that was programmed to translate 15 cm backward across a range of perturbation velocities. We used a range of perturbation velocities in an attempt to elicit each subject's repertoire of postural recovery strategies (i.e., ankle, hip, and step). We added catch trials consisting of forward directed perturbations (15 cm/s) and control trials, where the plate did not move, to minimize anticipation effects. The information obtained from the catch and control trials was not incorporated into the results presented in this article. The perturbation parameters defining the testing conditions are summarized in Table 1. The perturbation velocities for young adults ranged from 20 to 70 cm/s, and from 15 to 60 cm/s for the older adults. The highest perturbation velocity (70 cm/s) was not used with the older participants for safety reasons. Furthermore, the data obtained from the 15 cm/s condition in older adults, and from the 70 cm/s condition in younger adults, were excluded from further analyses. Thus, the data presented in this study were obtained from equivalent perturbation conditions (i.e., 20, 30, 40, 50, and 60 cm/s) for young and older adults.

Table 1. Perturbation Parameters in Each Condition

Condition	Displacement	Direction	Velocity Young	Velocity Older
0	15 cm	Backward	N/A*	15 cm/s
1	15 cm	Backward	**20 cm/s**	**20 cm/s**
2	15 cm	Backward	**30 cm/s**	**30 cm/s**
3	15 cm	Backward	**40 cm/s**	**40 cm/s**
4	15 cm	Backward	**50 cm/s**	**50 cm/s**
5	15 cm	Backward	**60 cm/s**	**60 cm/s**
6	15 cm	Backward	70 cm/s	N/A
7 catch	15 cm	Forward	15 cm/s	15 cm/s
8 control	0 cm	No movement	0 cm/s	0 cm/s

Note. Units in **boldface** indicate the testing conditions used for comparison
*N/A = not applicable.

Subjects were exposed to 6 trials at each of eight conditions for a total of 48 trials. The order of presentation followed a "pseudo-random" design whereby less severe perturbations were presented within the first 8 trials, and the order of the remaining 40 trials was fully randomized. This protocol ensured that participants would not be exposed to the more severe disturbances early in the test session. The less severe conditions were defined as the first four perturbation velocities for each age group. For younger adults, perturbations to a maximum velocity of 50 cm/s were used in these initial trials; for older adults, the maximum perturbation velocity used for the early trials was 40 cm/s. The subjects performed the math task in half of the trials, and the order of the math task trials was randomized independent of the order of perturbations. The math task involved counting backwards by threes from an arbitrary starting number greater than 100. A different starting number was given in each math trial.

Subjects began counting prior to the onset of data collection and continued until they were instructed to stop. They were also told to count as quickly and as accurately as possible and to continue counting through the plate movement. Subjects were also instructed to avoid using a step to recover their balance. These instructions were repeated regularly.

Data were collected over an 8-second interval. Plate movement was programmed to trigger at 4 seconds from the start of data collection in each trial. The subjects were unaware when data collection was initiated and, thus, could not predict when plate movement would occur. They stood with one foot on each of two translating forceplates and wore a lightweight climbing harness that attached to a low-friction overhead track to ensure safety in the event of a slip or a fall. They also wore a custom-designed microphone headset for collection of the vocal signal. Data collection was initiated when subjects stood motionless and without lean.

Our pilot work indicated that there was a noticeable learning effect for the counting task from the early trials to the end of the testing session. Most specifically, the speed of counting (as inferred from interverbalization subtraction duration) increased with practice. Thus, we included a practice session for the counting task prior to the onset of data collection to standardize counting speed between subjects. In this practice session, subjects performed the counting task across 10-second intervals. The number of verbal responses and the accuracy of responses were recorded. Data collection did not proceed until subjects were consistent in the number of verbal responses and free from counting errors for three consecutive practice trials. The average number of trials used to obtain this practice effect was 6.9 and ranged between 5 and 8 trials. All subjects completed the entire testing session, including the practice counting session and intermittent rest intervals, in about one hour.

Instrumentation

Perturbations were delivered using a dual-plate translating forceplate system (designed by Dave Brumbley, University of

Oregon, Institute of Neuroscience technical group) that was capable of movement in two directions (forward and backward) across a range of velocities and amplitudes. The input waveform produced either a positive linear ramp translation (forward plate movement) or a negative linear ramp translation (backward plate movement). The amplitude of translation remained fixed at 15 cm, but the duration of translation was adjusted to meet the perturbation velocities used in this study. The forceplates were electronically locked to translate synchronously. Analog outputs from a linear potentiometer and the net vertical ground reaction force were collected from each plate. These data were digitally sampled at 500 Hz. Analog output from the microphone headset was digitized at 11,000 Hz using an 8 bit A/D sound card (Creative Technology, Milpatis, CA). The potentiometer signal was overlaid with the audio signal to facilitate data analysis of the performance on the secondary task.

Kinematic data were recorded using the WATSMART motion analysis system (Northern Digital Equipment, Waterloo, ON, Canada) at a sampling frequency of 100 Hz. Two cameras were placed to obtain a sagittal view of the subject. Six infrared (IRED) markers were placed on the subject's body at locations approximating segment endpoints: toe, heel, ankle, knee, hip, and shoulder. The two-dimensional position coordinates were low-pass filtered at 3 Hz using a fourth order Butterworth digital filter. Filtered coordinates defining the foot, shank, thigh, and HAT (head, arms and trunk) were then combined with anthropometric data (11) in a four-segment model to obtain position coordinates for the whole body center of mass (COM) as follows:

$$COM = m1_{(x)} + m2_{(x)} + m3_{(x)} + m4_{(x)} / m1 + m2 + m3 + m4,$$

where m = segment mass and x = horizontal location of segment COM.

The behavioral responses to the perturbation were categorized as either feet-in-place or stepping responses based on a video record of the testing session and by using ground reaction force data collected from the forceplates. The feet-in-place responses were further categorized into ankle or hip strategies using the amount of hip flexion incorporated into the recovery strategy. We quantified the amount of hip flexion used in each feet-in-place response and calculated quartile scores for the range obtained. The amount of hip flexion ranged between 3.13 and 83.27 degrees, with quartile scores of 13 degrees and 26 degrees for the lower and upper quartiles, respectively. All feet-in-place responses having less than the lower quartile limit of 13 degrees were labeled as ankle strategies; everything above the upper quartile of 26 degrees was considered to be a hip strategy. The step responses were confirmed by the vertical ground reaction force signals from each plate. A step was defined as complete unweighting of the foot from the plate surface for at least 50 ms, causing movement that affected the size of the base of support. Step onset was determined as the point at which the vertical force recording reached zero under the stepping foot.

Data Analysis

Attentional demands of postural recovery.—The attentional demands of postural recovery were assessed from the accuracy and speed of the counting task for the period prior to and following the perturbation. Accuracy was determined from the number of errors in each trial; counting speed was inferred from the time interval between verbalizations (i.e., longer verbalization duration for slower counting speeds). The verbalization interval was obtained from the digital waveform of the verbal signal and represents the period of time from the onset of one verbalization to the onset of the next verbalization. A change in counting speed was assessed by comparing the subtraction duration value for the verbalization directly preceding the onset of the perturbation to the subtraction duration for the first verbalization following the perturbation. Trials in which subjects stopped counting as soon as the perturbation was delivered were excluded from further analyses. The data from two older adults were eliminated due to noise interference and/or inaudible signal quality.

Four questions were of interest: (a) Does recovering from a balance disturbance require attentional resources? (b) Is postural recovery any more demanding for an older adult than for a younger adult? (c) Do the specific strategies of postural recovery (ankle, hip, step) differ in their attentional demand? And, (d) do the attentional demands associated with a particular recovery strategy differ between age groups? The first two questions were assessed using 2 × 2 (Age × Interval [pre/post perturbation]) repeated measures analysis of variance (RM ANOVA), with subtraction duration score as the dependent variable. Because data from 2 older subjects were eliminated due to noise interference and/or inaudible signal quality, 23 subjects ($n = 8$ older adults and $n = 15$ younger subjects) contributed to this analysis.

The hip strategy was not a prevalent response among older adults, with less then 5% of all responses in this age group being categorized as hip strategies. Thus, analysis for the third question was restricted to young adults. A one-way RM ANOVA using post–pre perturbation subtraction duration difference scores from each of the ankle, hip, and step responses was used to assess whether the specific strategies of postural recovery differ in their attentional demand. The dataset used for this analysis was restricted to those subjects ($n = 5$) who used each type of recovery strategy in their repertoire of recovery responses.

The final question addressed whether the attentional demands associated with a particular recovery strategy differed between age groups. Again, because of an inadequate number of observations among older adults, the hip strategy was excluded from this question. A 2 × 2 (Age × Strategy) RM ANOVA using the post–pre perturbation difference scores from the ankle and step strategies was used to assess whether the attentional demands of the ankle or step strategy differed between age groups. The dataset in this second analysis was restricted to those subjects showing both strategies. There were 12 subjects in this dataset (7 young adults and 5 older adults).

Effect of a secondary cognitive task on postural recovery.—This portion of the study examined the effect of performing an attentionally demanding task on postural recovery in young versus healthy older adults. We first examined whether the performance of a cognitive task differentially affects the type of movement strategy used by young and older adults to regain balance. To answer this question we compared the type of recovery strategies used when the cognitive task was added with the strategies used when there was no cognitive task requirement. All subjects contributed to the dataset used for this analysis.

Following this, we compared the effects of the cognitive task on kinematic variables related to the control of the COM in the feet-in-place recovery strategies in young and older adults. Due to an inadequate number of observations, statistical analyses could not be performed for data relating to the hip strategy; thus, analyses of feet-in-place responses were restricted to the ankle strategy. The effect of a secondary cognitive task on the ankle strategy in young and older adults was assessed using the following measures of COM kinematics: (a) the maximum position that the COM reached, and (b) the time required to reach this position. The maximum COM position indicates how closely the COM approaches the base-of-support limit and provides information on the available margin of safety. The time to maximum COM position indicates the temporal requirements of reversing the forward COM displacement. A 2 × 2 (Age × Task [no math/math]) RM MANOVA was conducted using both measures to answer this question.

For stepping responses, two measures were used to infer the effects of the secondary cognitive task: (a) the time to step, and (b) the location of the COM within the base of support when the step occurred. The latency to step indicates how quickly the subject stepped following an attempt to keep the feet in place. The location of the COM at the onset of stepping indicates whether the COM position has exceeded the horizontal limits defined by the base of support, or whether stepping was initiated early when the COM was still within the boundaries of the base of support. A 2 × 2 (Age × Task [no math/math]) RM MANOVA was used to assess the effect of the secondary cognitive task on the stepping response. In all cases, follow-up univariate RM ANOVAs were conducted when the multivariate tests produced significant results.

The dataset used to assess the effects of a cognitive task on the ankle strategy comprised 14 subjects ($n = 7$ young adults [YA] and $n = 7$ older adults [OA]), and that used to determine the effects on step responses comprised 22 subjects ($n = 12$ YA and $n = 10$ OA). The number of subjects contributing to each dataset reflects the number of subjects who demonstrated the behavioral response of interest (i.e., feet-in-place or stepping) in each of the no-math and math conditions.

Results

Attentional Demands of Postural Recovery

This study first addressed whether recovering from a balance disturbance is attentionally demanding, and whether attentional demands are age dependent. These questions were answered by comparing the accuracy and speed of backwards counting for the intervals prior to and following the perturbation. Math accuracy did not differ between age groups or between the pre/post-perturbation intervals. A 2 × 2 (Age × Interval (pre/post)) RM ANOVA on subtraction duration scores, however, revealed significant main effects for age and interval [$F(1,21) = 5.84, p < .05$; $F(1,21) = 24.31, p < .05$]. These findings indicated that subtraction duration was significantly longer in older adults compared to younger adults and that postperturbation subtraction duration was significantly longer than preperturbation subtraction duration. There was also significant interaction between age and interval [$F(1,21) = 4.82, p < .05$]. Simple main effects revealed that the subtraction duration scores in the preperturbation intervals were not significantly different between young and older adults; however, the postperturbation subtraction duration was significantly greater in older adults. Figure 1 compares pre- and postperturbation subtraction duration in young versus older adults. As shown, young and older adults count at a comparable speed prior to the perturbation; however, age-related differences do become apparent in the postperturbation interval. These results suggest that recovery of stability following an external perturbation is attentionally demanding, and that attentional demands associated with postural recovery increase with age.

A third analysis compared the attentional demands associated with the three movement strategies (ankle, hip, and step) used to recover stability. As indicated previously, this analysis was limited to young adults. There was no significant difference in pre/post difference scores among the three movement strategies, suggesting that all three strategies require the same amount of attentional resources in this age group [$F(2,8) = .949, p > .05$].

The final analysis compared the attentional demands of the ankle versus the stepping strategy in young versus older adults. The results of a 2 × 2 RM ANOVA (Age × Strategy [ankle/step]) indicated that there were no significant interaction or main effects when either the ankle or stepping strategies were used to recover balance. However, the shift from ankle to stepping produced a substantially larger difference score in older adults (M ankle = 467, SD = 958 ms; M step = 761, SD = 1048 ms) compared to younger adults (M ankle = 570, SD = 539 ms; M step = 487, SD = 313 ms). Because the high within-group variability and small sample size ($n = 7$ YA, $n = 5$ OA) reduces the power of the statistical test (12), we used a follow-up independent t test to further address the attentional demands of stepping using a larger sample size. This larger sample comprised all subjects who used a step to recover their balance ($n = 14$ YA, $n = 10$ OA). However, the data from two older adults who did use a step to recover their balance could not be used in this analysis because of poor signal quality. Thus, the dataset for this follow-up analysis comprised 22 subjects ($n = 14$ YA, $n = 8$ OA). The results were nonsignificant [$t(20) = -1.75, p > .05$]; however, a comparison of the means suggested a trend toward higher attentional demands for stepping in older adults compared to younger adults. This trend is shown in Figure 2, where the subtraction duration difference scores for the ankle and step strategies are presented for each age group. As illustrated, the trend toward an age-dependent difference does not become apparent until the stepping strategy is used.

Effect of Secondary Cognitive Task on Postural Recovery

The second purpose of this study was to determine the effect of performing an attentionally demanding cognitive task on auto-

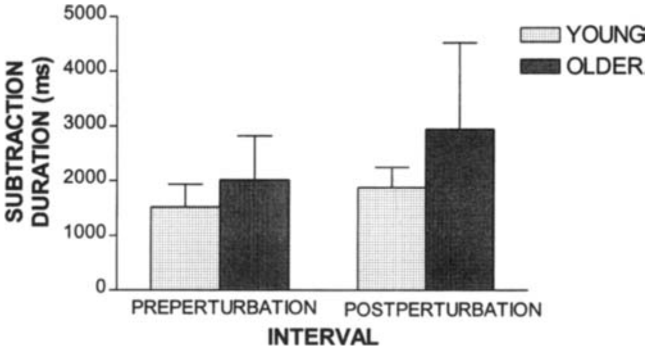

Figure 1. Preperturbation and postperturbation subtraction duration scores in young and older adults.

matic postural responses in young and older adults. Before examining the effect of adding a secondary task, it was essential to first determine whether the type of recovery strategy adopted by older adults differed from that of younger adults when balance was challenged. These findings are illustrated in Figure 3. The data were obtained from trials that did not have the secondary task constraint and represent those trials from which the behavioral response could be classified as being ankle, hip, or step. Forty-seven percent of the total "no-math" trials in younger adults and 70% of these trials in older adults fell into one of the three classifications. The greater proportion of classified strategies among older adults was due to the frequency of the step response in this age group. The results of a chi-square test of association indicated that the prevalence of each behavioral response is significantly different between older and younger adults [χ^2 (2, $n = 212$) $= 97.05$, $p < .05$]. For the same range of velocities, about 20% of the behavioral responses in no-math trials in young adults were classified as hip strategies (> 26 degrees); however, hip strategies were only seen in about 2.5% of the trials in older adults. The dominant response used by older adults was the stepping strategy, which was used more than 60% of the time. Young adults only stepped in about 10% of the trials. The prevalence of the ankle strategy was also markedly greater among younger adults (16%) than among older adults (5%) (Figure 3).

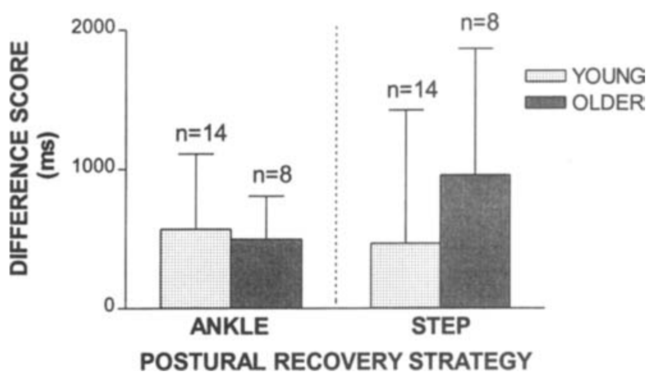

Figure 2. Post–pre subtraction duration difference scores for the ankle and step strategies in young and older adults. Data are obtained from the difference between the postperturbation and the preperturbation subtraction duration.

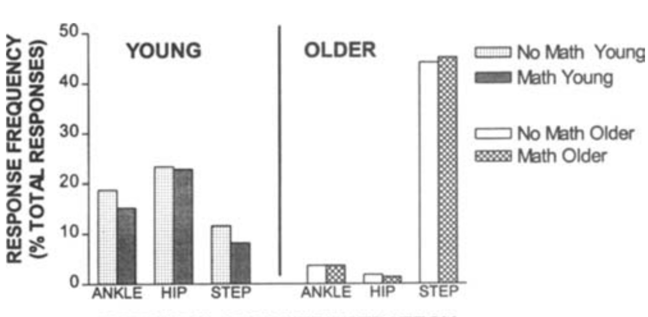

Figure 3. Prevalence of the ankle, hip, and step strategy in each age group. These results were obtained from trials that did not have the secondary task constraint and represent behavioral responses that could be classified as being ankle, hip, or step.

Does performance of an attentionally demanding cognitive task change the type of movement strategy used for postural recovery. Figure 4 illustrates the effect of adding a secondary task on the type of recovery strategy used by young and older adults and shows that the secondary task does not affect the choice of recovery strategy in either age group.

Does the secondary task differentially influence the control of the COM when the ankle strategy is used in young versus older adults. The results of a 2 × 2 repeated measures MANOVA revealed that the main effect of task and the interaction between age and task were nonsignificant. There was, however, a main effect for age [(Wilks' lambda = .23, $F(2,11) = 18.11$, $p < .05$]). Follow-up univariate ANOVAs showed that the age groups differed on both dependent variables [$F(1,12) = 5.94$, $p < .05$; $F(1,12) = 11.75$, $p < .05$ for the measures of time to peak COM displacement and maximum COM position, respectively]. In particular, the time to reach peak COM displacement was longer in older adults than in young adults, and the maximum COM position obtained was further from the limits of the base of support in older adults than in younger adults. Figures 5A and 5B show the effect of age on each of the dependent variables describing the ankle strategy. As young adults are more likely than older adults to use an ankle strategy following more severe disturbances than do older adults, it is probable that the differences observed reflect the effect of the perturbation on displacing the COM, and not any age-related differences in postural control underlying the ankle strategy.

Effect of Secondary Task on Step Strategy

A final question addressed in this study was whether a secondary task affected the step strategy differently in young versus older adults. Results of a 2 × 2 repeated measures MANOVA revealed a main effect for task, indicating that a cognitive task does influence the step response [Wilks' lambda = .65, $F(2,19) = 4.91$, $p < .05$]. The interaction between age and task, however, was nonsignificant. Thus, while performance of the secondary task did affect the stepping response, this effect was not dependent on age. The main effect for age was also nonsignificant. Univariate ANOVAs showed that the COM position at step onset was significantly affected by task [$F(1,20) = 10.34$, $p < .05$], whereas the time to step onset was not [$F(1,20) = .483$, $p > .05$]. Our results indicated that both younger and older adults initiated the step response when the COM was further from the limits of the base of support in the math condition than in the no-math condition. Descriptive statistics for the mea-

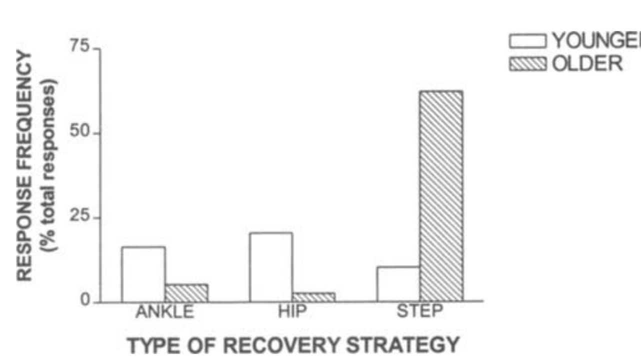

Figure 4. Effect of a secondary cognitive task on the type of recovery strategy used in each group.

sures used to describe the kinematics of the step response are summarized in Table 2.

Discussion

This study examined the effect of age on the relationship between attentional demands and postural recovery. We expected that recovery of postural stability would be more attentionally demanding for older adults than for younger adults because of inefficiencies produced by age-related impairments within the systems that are critical to postural control (13). In addition, we expected that older adults would adopt a hip or stepping strategy more frequently than do young adults. We further expected that the tendency to rely on these more complex strategies for postural recovery would be more prevalent during the performance of a secondary attentionally demanding task.

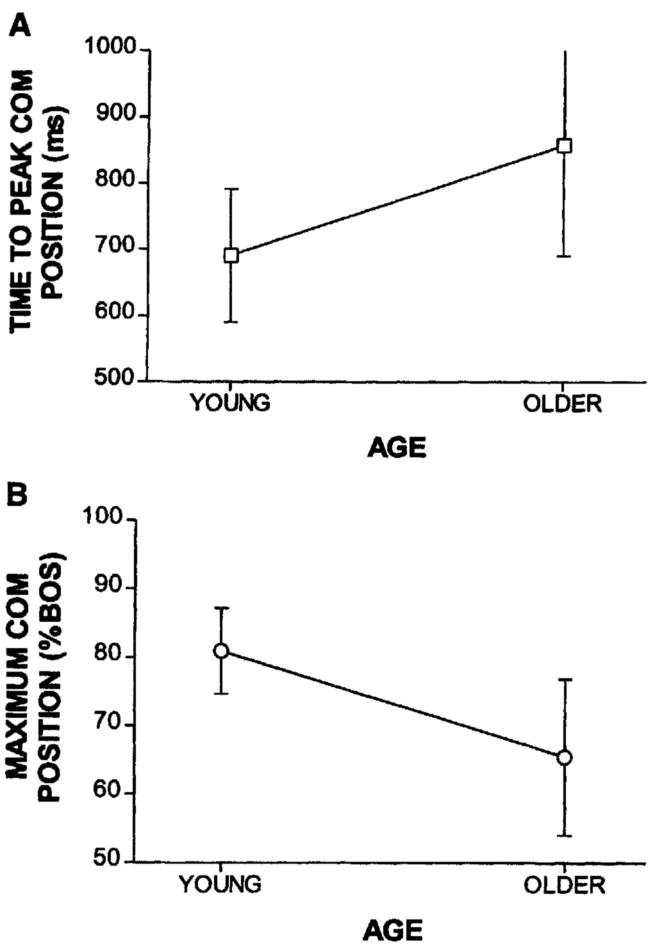

Figure 5. The effect of age on selected variables of COM kinematics in the ankle strategy. **A**, time to peak COM position; **B**, maximum COM position reached. Data are presented as the mean and standard deviation within each age group.

One of the primary questions addressed was whether the attentional requirements associated with recovery of stability are greater for older adults than for young adults. Our results support our hypothesis that postural recovery, considered to be an automatic task, actually requires attentional resources. In addition, as we predicted, attentional demands associated with recovery of stability are greater in older adults than in young adults. Lajoie and colleagues (2) demonstrated that older adults devote a greater proportion of their available attentional capacity than do younger adults to postural tasks associated with upright stance and locomotion. Our research extends their findings to the application of postural recovery and confirms that recovery from an external perturbation is more attentionally demanding for older adults than for younger adults.

Our results also indicate that, as the velocity of the balance disturbance increases, older adults are more likely to use a stepping response than younger adults. This finding is particularly compelling given our instructions to all participants to avoid stepping. These results imply that older adults tend to use the stepping response for a fall prevention strategy more often than do young adults. This finding is consistent with other researchers who have reported an increased tendency to step among older adults (14–16).

In young adults, attentional demands did not vary with the type of movement strategy used for postural recovery. This did not support our hypothesis of an attentional continuum associated with a continuum of movement strategies used for postural recovery. It is possible that the measures of attentional demand used in this study were not sensitive enough to indicate task-specific changes in the allocation of attentional resources in this age group. In addition, it is possible that a different type of cognitive task—for example, a visual spatial orientation task—might have had a more pronounced influence on postural recovery. It is also possible that the technique of identifying postural recovery strategies was not sensitive enough to appropriately differentiate feet-in-place responses as being either ankle or hip strategies. We are now examining task-specific changes in muscle response amplitudes to determine if this is a more sensitive indicator of change.

Our results do suggest that there is an attentional continuum associated with changes in movement strategies used for postural recovery in older adults. This age-related difference in attentional demand appears to be most prevalent for compensatory

Table 2. Descriptive Statistics for Stepping Response in Young and Older Adults

	Young Adults				Older Adults			
	Time to Step (ms)		COM pos (%BOS)		Time to Step (ms)		COM pos (%BOS)	
	No Math	Math	No Math	Math	No Math	Math	No Math	Math
MEAN	448.92	494.53	97.95	91.28	529.66	425.85	93.1537	90.73
SD	194.66	260.87	10.03	9.51	268.45	91.45	10.58	9.88
MIN	258.35	281.03	81.35	75.13	323.73	323.67	83.212	77.71
MAX	866.51	1109.1	111.1	106.29	1221.48	570.18	115.02	103.41
N	12	14	12	14	10	10	10	10

stepping. The fact that older adults use a stepping strategy more frequently than young adults is particularly surprising in light of the possibility that stepping is more attentionally demanding than feet-in-place strategies. It may be that older adults perceive the perturbations to be a greater threat to balance than do young adults and change strategies in response to those perceptions. More work is needed to understand this finding.

Based on previous findings, we expected that postural control would be affected by selective commitment of attention toward a cognitive task (8,9). We anticipated that any effect of the cognitive task would be seen in selected kinematic variables related to the control of the COM and, consequently, in the type of recovery strategy used to prevent instability (i.e., steps occur when the COM exceeds the base of support [BOS]). Our findings indicate that performance of an attentionally demanding cognitive task does not lead to a change in the type of strategy used for recovery. For both young and older adults, however, some kinematic parameters of the compensatory step response were affected by the increase in attentional load.

It is already established that when the COM exceeds the limits of the BOS, a step must be taken to prevent a fall (6). This study extends our understanding of the contexts under which steps are taken to recover stability. Our results demonstrate that stepping also occurs when the COM is within the BOS, and that this most often occurs among older adults in the dual-task condition. Is there a relationship between the finding that older adults are more prone to stepping when their balance is challenged and the finding that there is an increased rate of falls in older adults? Our results suggest that older adults favor stepping as a fall prevention strategy and, especially in a dual-task situation, take a step prior to the COM exceeding the BOS. However, our results indicate that stepping is a more attentionally demanding strategy for older adults than young adults. Therefore, in a dual-task context, stepping may in fact promote postural instability and falls if insufficient attentional resources are allocated to ensure a safe step.

It is now fairly well established that postural control is an attentionally demanding task. The results of this study support and extend this finding by confirming that recovery from an unexpected perturbation also requires attentional resources. Furthermore, this study suggests that the extent of the attentional resources required may depend on both age and type of movement strategy used to recover a stable position. The authors acknowledge that, due to the nature of the older adult sample used in this study (i.e., healthy with no balance impairments), the results do not generalize to a population of elderly adults. Thus, we are currently extending this study to integrate frail and balance-impaired older adults to examine whether inability to allocate sufficient attentional resources during stepping in a dual-task condition is a major factor in falls in these individuals.

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