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Age Differences in Postural Stability Are Increased by Additional Cognitive Demands

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We report an investigation of postural stability in two groups of volunteers (mean ages of 57 and 77). Participants were required to stand on a force platform while performing five cognitive tasks: (1) random digit generation, (2) Brooks' spatial memory, (3) backward digit recall, (4) silently counting from 1–100, and (5) counting backward in threes (aloud). There was also a control condition in which there was no cognitive task. Postural stability was adversely affected by age in all conditions. Moreover, the difference between the two age groups was significantly greater when performing tasks 2 and 3, in comparison with the age difference in the control condition. Regression analyses revealed that the effect of age on postural stability while performing these particular tasks remained significant even after the following measures were included in the regression: postural stability in the control condition, cognitive performance, intelligence, and speed. We suggest that age differences in postural stability are increased by cognitive tasks requiring use of the visuo-spatial sketchpad component of working memory.

THE high prevalence (and serious consequences) of falls among older people is well documented. For example, Blake et al. (1988) reported that 35% of individuals aged over 65 in a large community sample suffered one or more falls in the previous year. Fear of falling is also common (even in those who have never fallen), and this fear is sufficient to restrict the activity of 42% of over-75s living at home (Downton & Andrews, 1990).

A possible link between the tendency of old people to fall and their inability to control postural sway was first suggested by Sheldon (1963). Several studies have since provided evidence to support such a link. Fernie, Gryfe, Holliday, and Llewellyn (1982) observed that postural sway was significantly greater for those who fell one or more times in a year than for those who did not fall (participants aged over 63). In Downton and Andrews' (1990) study, 49% of the over-75s suffered occasional or frequent subjective feelings of postural instability, and this was associated with having fallen in the previous year. When sway was measured with a portable force plate, these participants were found to sway more, demonstrating an association between subjective feelings of instability and objectively impaired balance (Downton, Sayegh, & Andrews, 1991).

Maintaining a stable upright posture is a complex process, summarized by Downton (1990) as follows: Sensory information is provided by vision, proprioception, and the vestibular system. This input is processed centrally by several areas of the brain, including the cerebellum, brainstem, basal ganglia, and sensorimotor cortex. Postural control is then effected by limb and trunk muscles which receive impulses via the spinal cord and peripheral nerves. Age-related impairments have been proposed at every stage of the postural control system (Lord, Clark, & Webster, 1991; Stelmach & Worringham, 1985; Woollacott, Shumway-Cook, & Nashner, 1982). In terms of input, there is deterioration of the peripheral sensory processes (visual, proprioceptive, and vestibular). On the output side, slowing of peripheral nerve conduction velocity and reduction of muscle bulk have both been demonstrated in elderly people. Evidence for impairment of central integrative processes comes from a study by Teasdale, Stelmach, Breunig, and Meeuwsen (1991b). They measured postural stability under reduced sensory conditions (from vision to no vision), and augmented sensory conditions (from no vision to vision). In both cases, older participants adapted more slowly to the transitions than younger participants, indicating a deficit in reconfiguring postural set after a change (either positive or negative) in sensory information.

Postural stability declines with age, but the association is not perfect. Thus, Anstey, Stankov, and Lord (1993) observed a correlation between age and body sway of only r = .30 for participants aged 65–91. However, the relationship may be stronger in situations of reduced or conflicting sensory input, or when balance is actively disturbed (Woollacott et al., 1982). For example, Wolfson et al. (1992) found that standing balance of older participants was particularly impaired in comparison with younger participants when visual and tactile-proprioceptive inputs were occluded or distorted (see also Teasdale, Stelmach, & Breunig, 1991a). The difference between standing balance of older and younger participants is similarly exaggerated by physical perturbations, whether these are imposed by the experimenter (slow ankle rotations; Stelmach, Teasdale, Di Fabio, & Phillips, 1989) or generated by the participant under instructions (arm-swinging; Stelmach, Zelaznik, & Lowe, 1990).

Teasdale, Bard, LaRue, and Fleury (1993) have recently argued that a major determinant of postural instability in old age is reduced attentional capacity and/or a defect in the allocation of available resources. This is based on studies using a reaction time (RT) probe technique in which young and elderly participants were asked to respond to unpredictable auditory stimuli by pressing a handheld button as fast as possible. Under normal standing conditions, probe RT was slower for the elderly than for the young. When the postural control task increased in difficulty (e.g., from eyes open to eyes closed, or from standing on a normal surface to a foam surface), probe RT increased, but more so for the elderly than for the young. This was interpreted as indicating that difficult postural control tasks require greater attentional resources; since these resources are depleted in the elderly, probe RT increases more as a result. Another explanation (but not necessarily mutually exclusive) is that with the loss of visual, proprioceptive, and vestibular sensitivity in old age, more of the elderly's attention is required to maintain postural stability, particularly in less stable situations (see Stelmach et al., 1990). Whatever the explanation, there remains the issue of whether the probe RT interactions observed by Teasdale et al. (1993) reflect anything more than generalized age-related slowing (Cerella, 1985; chapter 7 of Salthouse, 1991). In other words, factors that increase RT for the young usually produce a proportional increase in RT for the old (i.e., greater in absolute terms, but equivalent in relative terms).

Teasdale et al.'s (1993) demonstration of interference from a difficult standing task on the performance of a cognitive task is reminiscent of a study by Kerr, Condon, and McDonald (1985). The latter authors argued as follows: (1) visual information is important in postural control; (2) visual spatial imagery involves the visual system; (3) maintaining a difficult posture should interfere with visuo-spatial memory, but not with verbal memory. This is exactly what Kerr et al. (1985) found. Student participants were asked to perform Brooks' (1967) spatial and nonspatial memory tasks. In the spatial version, the task was to listen to, and then repeat back, the locations of digits in an imaginary 4 × 4 grid. In the nonspatial version, the directions right, left, up, and down were replaced by the words quick, slow, good, and bad. Both tasks were performed either while sitting or while standing in the Tandem Romberg position (i.e., with the heel of the front foot directly ahead of the toes of the back foot). As Kerr et al. predicted, the difficult standing task produced a decrement in recall scores for the spatial task but not for the nonspatial task.

In the present study, we investigated postural stability in younger and older volunteers over a range of cognitive tasks (including Brooks' spatial memory). In contrast with earlier work, we employed sensitive measures of *both* postural stability and cognitive performance. Age-related impairments were expected when either task (postural or cognitive) was performed alone. The important question was whether or not older participants would show greater interference than younger participants when the postural and cognitive tasks were performed together. Age differences are often greater under dual task conditions than under single task conditions, particularly when one of the measures is reaction time (e.g., Somberg & Salthouse, 1982). However, the increase is usually proportionate, that is, the age difference under dual task conditions is linearly related to the age difference under single task conditions (e.g., McDowd & Craik, 1988). In this study, we addressed the scaling issue by statistically controlling for age differences in single task performance. Thus, we conducted regression analyses on the dual task data, with the single task data and age as predictors. A significant independent contribution to the variance from age is evidence of a disproportionate effect of age on maintaining postural stability while performing a cognitive task. Note, finally, that the present participants were selected from a well-documented panel of volunteers for whom several background measures were available. This allowed us to examine the extent to which the influence of age was independent of its effect on intelligence (see Rabbitt, 1983) and/or speed (see Salthouse, 1992b).

Five cognitive tasks were chosen for investigation, each of which involves at least one component of working memory. Baddeley and his colleagues have described working memory as a system for temporarily holding and manipulating information (Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley & Lieberman, 1980). It is used in a wide range of cognitive tasks, such as learning, reasoning, and comprehending. The working memory model currently comprises a central executive (CE) and two slave systems, the phonological loop (PL) and the visuo-spatial sketchpad (VSSP). The CE is a limited capacity attentional system which coordinates and supervises the modality-specific slave systems, and integrates information from them. The PL has two subsystems, namely, a phonological store that holds speech-based information for 1.5–2s, and an articulatory rehearsal process based on inner speech. Finally, the VSSP is responsible for setting up and manipulating visuo-spatial images. Although the precise effects of aging on these various components are unclear, age-related deficits in working memory tasks are well established in the literature, from Welford (1958) to Salthouse (1992a).

The cognitive tasks in the present study, and the working memory components thought to be involved (from Baddeley, 1986), were as follows:

- *Random digit generation.* This activity places significant demands on the CE of working memory (Baddeley, 1986).
- *Brooks' spatial memory.* This task requires the use of the VSSP.
- *Backward digit recall.* On the grounds that forward digit recall requires the PL (Baddeley, 1986), it could be assumed that this is the component most involved here. However, note that more recent evidence suggests that the VSSP is used in backward digit recall (Li & Lewandowsky, 1993, 1995).
- *Silent counting.* This occupies the articulatory rehearsal subsystem of the PL.
- *Counting backward in threes.* This task places demands primarily on the phonological store of the PL.

The main question of interest is which (if any) of these cognitive tasks causes greater interference with postural stability in older participants, in comparison with younger participants. The precise pattern of results obtained across the five tasks should enable us to identify possible task requirements or working memory components contributing to the effect. For example, if tasks 1, 2, 3, and 5 result in larger age differences in postural stability than task 4, then verbal responding may be a crucial factor. A role for the CE would be indicated by a specific effect for task 1, the VSSP by tasks 2 and 3, and the PL by tasks 4 and 5. One final possibility explored here is that the degree to which age differences in postural stability are increased by any cognitive task is determined by the size of the age-related deficit in cognitive performance.

METHOD

Subjects

Participants were selected from a panel of volunteers aged over 50 who were enrolled in a longitudinal study of cognitive aging (see Rabbitt, Donlan, Bent, McInnes, & Abson, 1993) at the University of Newcastle-upon-Tyne (North East Age Research). Each volunteer had responded to media advertisements and had visited the laboratory on at least three previous occasions. Data available from these group testing sessions (conducted between 1 and 3 years before the present study) included:

(1) Vocabulary scores from the Wechsler Adult Intelligence Scale–Revised (WAIS–R; Wechsler, 1981) and the Mill Hill Vocabulary test (Raven, 1965). The vocabulary subtest of the WAIS–R was adapted slightly for use with British subjects (maximum score = 74). The first part of the Mill Hill is a multiple-choice test in which participants are required to select the best synonym for a target from a set of six alternatives. In the second part, participants are asked to provide definitions of words. These vocabulary tests are performed without time limits.

(2) Intelligence scores from Scale 2, Form B of the Culture Fair Intelligence Test (Cattell & Cattell, 1960) and the AH4 test. The latter is a "group test of general intelligence, for use with a cross section of the adult population" (Heim, 1968) comprising verbal, arithmetical, and spatial multiple-choice questions. Both of these tests are speeded.

(3) Information processing speed scores from a letter coding task (total number of correct substitutions over 4 runs, each of 2 minutes) and a visual search task (total number of targets crossed out from 4 sheets of random letters, 2 min per sheet). See Maylor and Rabbitt (1994) for further details.

Potential participants on the North East Age Research panel were contacted by telephone and were asked if they would be willing and able to participate in a study which involved: (a) auditory stimuli and (b) standing unaided for most of the session. Volunteers were not recruited if they reported any difficulty in either hearing or standing. Additionally, they were excluded if they were aware of ever having suffered a stroke. There were 38 participants in the study; they formed two age groups (younger and older), with 5 men and 14 women in each age group. The mean age of the younger group was 57.1 years (SD = 1.7; range = 53.9–59.9). The older group had a mean age of 77.2 years (SD = 2.1; range = 74.3–81.6). The two age groups were matched as closely as possible in terms of their WAIS–R Vocabulary scores. Volunteers were each paid £4 (approximately $6) for participating in the present experiment.

In Table 1, the means for the two age groups for each of the measures described above are presented. The mean z-scores were produced by standardizing the scores prior to averaging across the two measures of each ability. Comparing these z-scores, younger and older participants were equivalent in terms of vocabulary (or crystallized intelligence), but differed significantly in terms of fluid intelligence (Culture Fair and AH4) and speed ($t(36)$ = –.17, 7.29, and 3.29, respectively), as expected (see Horn & Cattell, 1967).

Table 1. Means and Standard Deviations of Background Scores for the Two Age Groups

Test	Maximum Possible Score	Younger Group M	Younger Group *SD*	Older Group M	Older Group *SD*
Vocabulary					
WAIS–R[a]	74	51.68	6.22	51.47	6.06
Mill Hill[b]	66	38.74	6.28	39.58	6.51
Mean z-score[c]		–0.025	0.914	0.025	0.890
Intelligence					
Culture Fair[a]	46	31.58	4.77	20.90	6.11
AH4[b]	130	83.79	12.17	54.68	12.29
Mean z-score[c]		0.731	0.573	–0.731	0.660
Speed					
Letter coding[d]	—	240.11	35.67	185.63	46.98
Visual search[d]	—	219.90	27.15	201.37	40.28
Mean z-score[c]		0.407	0.526	–0.407	0.940

[a]WAIS–R and Culture Fair data collected in session 1.
[b]Mill Hill and AH4 data collected in session 3.
[c]The scores on the two measures of each ability were standardized and then averaged to produce the mean z-scores.
[d]Letter coding and visual search data collected in session 2.

Apparatus and Stimuli

Postural stability was monitored using SwayWeigh (obtained from Raymar Ltd, Unit 1, Fairview Estate, Henley-on-Thames, Oxon, RG9 1HE, UK). SwayWeigh is a low-cost apparatus for measuring weight distribution. It comprises electronic weighing scales set in a base that, for lateral measurements, allows one foot to be placed on the scales and the other foot on a fixed plate of equal height. The scales reading is divided by body weight to yield left-right weight distribution as a percentage of body weight. For anterior-posterior weight distribution, the balls of the feet are positioned on the scales and the heels on the fixed plate.

Percentage weight distribution (WD) readings obtained from SwayWeigh are directly related to the center of pressure (CP) in the relevant (lateral or anterior-posterior) direction. Thus, in the static case, leaning to one or other extreme (say, forward or backward) giving a WD range of 100%, corresponds to an anterior-posterior CP range defined by the front and back edges of the base of support (i.e., toes and heels). This, in turn, relates to a change in body center of mass (CM) position corresponding to the length of the foot. For example, with a foot length of 25 cm, a 4% difference in WD would imply a 1 cm difference in CM position. In the dynamic case (allowing for muscle forces involved in actively changing body CM position), CP excursions exceed those of the CM (Winter, Patla, & Frank, 1990). Accordingly, in the example given for SwayWeigh, a 4% change in weight distribution, in general, corresponds to a CM position change of less than 1 cm. Changes in the WD measure provided by SwayWeigh reflect the combined effects of CM position variation and active forces producing CM position change. Variability in WD, as estimated by the standard deviation, SD(WD), may thus be taken as an index of standing stability in the same way that the standard deviation of CP has been used (e.g., Winstein, Gardner, McNeal, Barto, & Nicholson, 1989); in both cases, lower values of standard deviation indicate greater stability.

In the present experiment, SwayWeigh was used to measure anterior-posterior WD. After standing with both feet on the scales to obtain a measure of body weight, participants were asked to stand on outline footmarks (outer edges 26 cm apart) with ankle joints approximately over the edge of the scales so that the heels were on the fixed plate and the balls of the feet on the scales. When standing upright, this produced a reading in the region of 50%. (The exact value was not important as the focus was on changes in WD.) On each run, SwayWeigh readings were sampled with a BBC Master microcomputer to an accuracy of 0.5% body weight for a period of 30 sec at 20 Hz and stored for subsequent analysis. The sampling program provided an audible warning at the beginning and end of each run.

Fixation points were small green circles (1 cm diameter) on an otherwise blank wall approximately 1.5 m in front of the participant. One was positioned at eye level when the participant was standing, the other at eye level when sitting.

A metronome was used to control the rate of stimulus presentation and response production in two of the cognitive tasks, namely, random digit generation and backward digit recall. This was placed slightly behind and to the left of the participant. The cognitive tasks were timed by a stopwatch. Participants' verbal responses were recorded on tape and transcribed later for analysis.

For Brooks' spatial memory task, five different sets of stimuli were produced. In each set, there were four stimuli of length 4, four of length 5, four of length 6, and four of length 7 (a total of 16 stimuli per set). Each stimulus was a list of instructions for placing consecutive numbers in a 4 × 4 grid. The first instruction was always "In the starting square put a 1." The starting square was the second row of the second column of the grid. The instructions continued: "In the next square to the right/to the left/up/down put a 2," "In the next square to the right/to the left/up/down put a 3," and so on to the end of the list (4, 5, 6, or 7 instructions). The directions (right, left, up, and down) were randomly chosen by hand with the restrictions that a number was never placed outside the grid or in a square already occupied. A large card was produced which illustrated a list length of 8; the upper panel showed a 4 × 4 grid with the numbers 1–8 occupying half of the squares, and the lower panel listed the corresponding instructions.

For the backward digit recall task, random number tables were used to generate sequences of 3, 4, and 5 digits (including zero). Within each sequence, no digit appeared more than once. Random number tables were also used in selecting large three-digit numbers from which to start the task of counting backward in threes.

Design and Procedure

Participants were tested individually in experimental sessions lasting approximately an hour. Each session began with the calibration of SwayWeigh (see above). This was followed by two identical runs of a simple 30-sec task in which the participant was required to watch the experimenter and copy a sequence of arm movements while standing as still as possible. The data from this task will not be reported here, although it can be noted that the arm movements resulted in identical adjustments to body-weight distribution in the younger and older age groups.

The present study, as summarized in Table 2, then began with the first run of the standing task performed alone (Standing; Single task conditions). Participants were required to stand on SwayWeigh with their arms by the side and to look straight ahead at the upper fixation point. The instructions were to remain as steady as possible. When the participant was ready, the experimenter pressed a key on the computer keyboard (which produced a beep) to begin the recording period of 30 sec. (The experimenter was seated slightly behind and to the left of the participant throughout the present study.) After the second beep from the computer, the participant was asked to step off SwayWeigh and to sit down. This task was repeated on completion of each of the five cognitive tasks, making a total of six runs of the standing task performed under single task conditions (again, see Table 2).

Table 2. Summary of Experimental Procedure
(Warm-up Trials Omitted)

Description	Task	Condition
Stand on SwayWeigh	Standing	Single
Random digit generation		
2 × seated [a]	Cognitive	Single
2 × standing [a]	Cognitive + Standing	Dual
Stand on SwayWeigh	Standing	Single
Brooks' spatial memory		
2 × seated (× 3 levels of difficulty)	Cognitive	Single
2 × standing (× 3 levels of difficulty)	Cognitive + Standing	Dual
Stand on SwayWeigh	Standing	Single
Backward digit recall		
2 × seated (× 3 levels of difficulty)	Cognitive	Single
2 × standing (× 3 levels of difficulty)	Cognitive + Standing	Dual
Stand on SwayWeigh	Standing	Single
Silent counting		
2 × seated	Cognitive	Single
2 × standing	Cognitive + Standing	Dual
Stand on SwayWeigh	Standing	Single
Counting backward in threes		
2 × seated	Cognitive	Single
2 × standing	Cognitive + Standing	Dual
Stand on SwayWeigh	Standing	Single

[a]Order = Seated-Standing-Standing-Seated for 20 participants; Standing-Seated-Seated-Standing for 18 participants.

The general procedure for all the cognitive tasks was as follows. First, warm-up trials were performed while seated. The cognitive task was then carried out four times, twice while seated and looking at the lower fixation point (Cognitive; Single task conditions), and twice while standing on SwayWeigh and looking at the upper fixation point (Cognitive and Standing; Dual task conditions). Participants were frequently reminded of the requirement to remain as steady as possible when standing. The order for the cognitive tasks was Seated-Standing-Standing-Seated for 10 younger and 10 older participants, and Standing-Seated-Seated-Standing for 9 younger and 9 older participants. The same order applied throughout the session.

All participants performed the five cognitive tasks in the same order:

(1) *Random digit generation.* — Participants were required to generate single digits as randomly as possible, but to do this in time with the metronome beating at a rate of 60 per minute. To appreciate the concept of randomness (and for that purpose only), participants were told to imagine a hat containing the digits 0–9, and to imagine dipping into the hat, pulling out a number, reading it, replacing it, shuffling the hat, and then repeating the process. Note that there was never any suggestion that this was literally how participants were expected to perform the task. As a warm-up, participants practiced the task for a minute. Each of the four experimental runs lasted a minute, with the experimenter telling the participant when to start and when to stop the task. Under dual task conditions, standing was monitored from 15 sec after the start of the cognitive task until 15 sec before the end (i.e., 30 sec).

(2) *Brooks' spatial memory.* — The layout of the grid, the location of the starting square, and the general task requirements were explained to the participant using the example card showing a list length of 8. The experimenter read each list of instructions at a standard rate of approximately 3 sec per instruction. After the last instruction, the participant was asked to repeat back the list exactly as it had been presented. For each participant, one of the five different sets of 16 stimuli was chosen at random such that two sets were used 7 times and three sets were used 8 times. The four lists of length 4 were used as a warm-up. In each of the four experimental runs, there were three lists, and these were presented in ascending order of length (5-6-7). Participants were always informed of the list length before it was presented. Under dual task conditions, standing was monitored for 30 sec from just prior to the first, second, or third instruction, depending on the list length (5, 6, or 7, respectively). Thus, participants were listening during the first 15 sec of the monitoring period and responding during the second 15 sec, irrespective of list length.

(3) *Backward digit recall.* — The experimenter read out a sequence of digits in time with the metronome beating at a rate of 40 per min. The participant's task was to repeat back the digits, again in time to the beat, but in reverse order. This was immediately followed by another sequence of the same length, without missing a beat. Four sequences of 3 digits were presented as a warm-up (e.g., "9 5 4 *4 5 9* 2 6 7 *7 6 2* 1 3 9 *9 3 1* 4 0 6 *6 0 4*," with the participant's response italicized). In each of the four experimental runs, there were 4 sequences of 3 digits, 4 sequences of 4 digits, and 4 sequences of 5 digits (always in that order). There were short breaks between groups of different sequence lengths during which the experimenter announced the next sequence length. In the dual task situation, standing was monitored during (approximately) the central 30 sec of the 36-, 48-, and 60-sec periods (minimum) required by the backward digit recall task, lengths 3, 4, and 5, respectively.

(4) *Silent counting.* — Participants were required to count as rapidly as possible from 1 to 100 without vocalizing. The experimenter indicated when to begin, and the participant called out "100" on reaching the target. Participants tried out the task once before beginning the four experimental trials. Under dual task conditions, standing was monitored for 30 sec from the experimenter's instruction to start counting.

(5) *Counting backward in threes.* — Participants were required to count backward aloud in steps of 3 as fast and accurately as possible, from a three-digit number provided by the experimenter. There was a warm-up run of 30 sec, followed by four runs of the same duration. The commands to start and stop counting backward in threes coincided with the beginning and end of the monitoring period in the dual task situation.

Data Analysis

As already noted, the measure of postural stability was SD(WD), that is, the standard deviation of weight distribution. This was derived from the 600 values of WD (percentage body weight on the SwayWeigh scales) recorded over each 30-sec monitoring period at 20 samples per second. Smaller values of SD(WD) were taken to indicate greater postural stability.

The main measures of interest in the cognitive tasks were as follows:

(1) *Random digit generation.* — Redundancy based on the frequency of successive pairs of digits, expressed as a percentage (see Baddeley, 1966). Note that this second-order redundancy measure has been shown to be sensitive to changes in the required rate of generation (Baddeley, 1966), to frontal lobe damage (Spatt & Goldenberg, 1993), and to normal aging (Van der Linden, Beerten, & Pesenti, 1994).

(2) *Brooks' spatial memory.* — Number correct, separately for list lengths of 5, 6, and 7. A response was scored as correct only if the entire list of instructions was reproduced completely without error, although exact wording was not essential.

(3) *Backward digit recall.* — Number of sequences out of 4 recalled both correctly and at the required rate (i.e., without missing a beat), separately for sequence lengths of 3, 4, and 5 digits.

(4) *Silent counting.* — Number of seconds required to count silently from 1–100.

(5) *Counting backward in threes.* — Number of correct subtractions completed in 30 seconds.

RESULTS

Cognitive Performance

Participants performed each task *twice* under single task conditions (seated) and *twice* under dual task conditions (standing). Practice was therefore included as a factor in the initial analyses of variance, but it did not interact significantly with either age or condition (single vs dual) in any of the analyses. The data were therefore averaged across the two occasions before performing the analyses reported below.

(1) *Random digit generation.* — Most participants were able to generate digits at the required rate, missing on average fewer than 0.4% of the metronome's beats. The exceptions were 3 younger participants (who missed 6%, 11%, and 21% of the beats) and 2 older participants (who missed 24% and 45% of the beats). Intrusions (e.g., "10") were very rare, with a mean rate of 0.2% in both age groups.

Redundancy based on successive pairs was the dependent variable in a two-way analysis of variance, with age group (2 levels: younger and older) as the between-subjects factor and task condition (2 levels: single and dual) as the within-subjects factor. There were significant effects of both age [$F(1,36) = 4.05$, $MS_e = 13.15$, $p < .03$] and condition [$F(1,36) = 5.41$, $MS_e = 2.59$, $p < .03$], but there was no interaction ($F < 1$) (see Note 1). From Table 3 it can be seen that younger participants generated digits more randomly (i.e., lower redundancy) than older participants, and that digit generation was more random under single task conditions than under dual task conditions.

(2) *Brooks' spatial memory.* — The number of correct responses was analyzed with the age and condition factors as above, but with the additional within-subjects factor of difficulty (3 levels: list lengths 5, 6, and 7). There were significant effects of age [$F(1,36) = 4.40$, $MS_e = 0.34$, $p < .03$] and difficulty [$F(2,72) = 18.98$, $MS_e = 0.10$, $p < .001$]. No other F-ratio exceeded 1. Table 3 reveals that younger participants were more successful than older participants and that performance declined with increasing list length.

(3) *Backward digit recall.* — Numbers of correct responses were analyzed with age, condition, and difficulty (3 levels: sequence lengths 3, 4, and 5) as between-, within-, and within-subjects factors, respectively (see Table 3 for the means). Again, younger participants performed significantly better than older participants [$F(1,36) = 3.32$, $MS_e = 3.57$, $p < .04$]. Participants were obviously less successful as difficulty increased [$F(2,72) = 138.20$, $MS_e = 0.44$, $p < .001$]. There were no other significant effects (all remaining Fs < 2.27).

(4) *Silent counting.* — In a two-factor analysis of variance, younger and older participants did not differ in their times for counting silently from 1–100 ($F < 1$). However, participants required significantly *more* time to count under single task conditions than under dual task conditions [$F(1,36) = 6.29$, $MS_e = 2.77$, $p < .02$]. There was no interaction between age group and task condition ($F < 1$). See Table 3 for the means.

(5) *Counting backward in threes.* — A two-factor analysis of variance on the number of correct subtractions made in 30 sec revealed that younger participants were more successful than older participants [$F(1,36) = 3.97$, $MS_e = 27.42$, $p < .03$]. There was neither an effect of condition, nor an interaction between age and condition (both Fs < 1.67). The means are shown in Table 3.

Table 3. Means and Standard Deviations of Scores on the Cognitive Tasks for the Two Age Groups Under Single and Dual Task Conditions

	Younger Group		Older Group	
	M	*SD*	M	*SD*
Random digit generation (% Redundancy based on pairs)				
Single	21.81	2.03	23.22	3.23
Dual	22.41	1.82	24.35	3.68
Brooks' spatial memory (Number correct out of 1)				
Single Length 5	0.816	0.342	0.711	0.303
Single Length 6	0.579	0.301	0.500	0.373
Single Length 7	0.526	0.424	0.289	0.303
Dual Length 5	0.763	0.348	0.553	0.438
Dual Length 6	0.658	0.336	0.447	0.405
Dual Length 7	0.447	0.438	0.316	0.380
Backward digit recall (Number correct out of 4)				
Single Length 3	3.737	0.609	3.579	0.607
Single Length 4	3.395	1.008	2.974	0.979
Single Length 5	2.237	1.206	1.500	1.027
Dual Length 3	3.711	0.585	3.342	0.783
Dual Length 4	3.316	0.916	2.947	0.999
Dual Length 5	2.211	1.110	1.526	1.196
Silent counting (Time taken in seconds)				
Single	38.32	8.39	40.22	8.55
Dual	37.35	8.34	39.27	8.83
Counting backward in threes (Number of correct subtractions)				
Single	15.16	3.81	13.13	3.57
Dual	15.87	3.59	13.11	4.22

To summarize the cognitive data, the younger participants performed significantly better than the older participants on all tasks except silent counting. Performance under single and dual task conditions only differed significantly for random digit generation (single more random than dual) and silent counting (single slower than dual). One explanation for this unexpected effect for silent counting is that participants may have been more aroused when standing. Finally, there were no Age × Condition interactions.

Postural Stability

SD(WD) from the six runs of standing under single task conditions (see Table 2) were averaged to produce an overall measure of postural stability under single task conditions. For each of the five dual task conditions, the postural stability data were similarly averaged across runs (2 in the case of random digit generation, silent counting, and counting backward in threes; 6 in the case of Brooks' spatial memory and backward digit recall (see Note 2). The overall means and standard deviations of SD(WD) for the two age groups in each condition are presented in Table 4.

In the same way as for the cognitive data, five separate two-way analyses of variance were conducted on the

SD(WD) data, with age group as the between-subjects factor and task condition (single vs dual) as the within-subjects factor in each case. The results were as follows:

(1) *Random digit generation.* — There was a significant effect of age group [$F(1,36) = 6.01$, $MS_e = 0.84$, $p < .02$], but no effect of condition ($F < 1$) and no interaction ($F < 1$).

(2) *Brooks' spatial memory.* — There was a significant effect of age group [$F(1,36) = 11.79$, $MS_e = 1.04$, $p < .002$], no effect of condition ($F < 1$), but there was a significant interaction between age and condition [$F(1,36) = 5.96$, $MS_e = 0.30$, $p < .02$].

(3) *Backward digit recall.* — There was a significant effect of age group [$F(1,36) = 11.47$, $MS_e = 0.86$, $p < .002$], a marginal effect of condition [$F(1,36) = 3.11$, $MS_e = 0.22$, $p < .1$], and an interaction between age and condition [$F(1,36) = 4.29$, $MS_e = 0.22$, $p < .05$].

(4) *Silent counting.* — There was a significant effect of age group [$F(1,36) = 6.38$, $MS_e = 1.18$, $p < .02$], but no effect of condition ($F < 1$) and no interaction ($F = 1.11$).

(5) *Counting backward in threes.* — There was a significant effect of age group [$F(1,36) = 6.43$, $MS_e = 1.25$, $p < .02$], but no effect of condition ($F = 2.67$) and no interaction ($F = 1.30$).

To summarize the above analyses, the younger participants were significantly more stable [i.e., smaller SD(WD)] than the older participants throughout. Participants tended to be more stable when recalling digits backward compared with single task conditions (see Table 4). However, this trend may be misleading in view of an effect to be discussed in detail below (namely, "slow drift"). For the moment, the important results to emphasize are the two interactions indicating that age differences in postural stability were significantly larger when performing the Brooks' spatial memory and backward digit recall tasks, in comparison with the single task conditions.

Table 4. Means and Standard Deviations of SD(WD) (Postural Stability in the Standing Task) for the Two Age Groups Under Single and Dual Task Conditions

		Younger Group		Older Group	
		M	*SD*	M	*SD*
Single		2.953	0.470	3.450	0.877
Dual	(Random digit generation)	2.821	0.673	3.354	0.932
Dual	(Brooks' spatial memory)	2.720	0.741	3.831	1.070
Dual	(Backward digit recall)	2.542	0.544	3.483	0.930
Dual	(Silent counting)	2.733	0.907	3.491	1.057
Dual	(Counting backward in threes)	3.018	0.870	3.820	1.192

Regression Analyses

A potential difficulty in interpreting the interactions observed between age group and single/dual task conditions is that younger and older participants were not matched for postural stability under single task conditions. Another issue is the extent to which the interactions in the analyses of postural stability are attributable to the fact that older participants were less successful than younger participants at the cognitive tasks (see Table 3). In order to take account of these baseline differences between age groups in both postural stability under single task conditions and cognitive performance under dual task conditions, we conducted regression analyses for the Brooks' spatial memory and backward digit recall tasks. We initially carried out hierarchical regressions, with mean SD(WD) under the two dual task conditions as the predicted variables. The predictor variables were added to the analyses in the following order: (1) mean SD(WD) under single task conditions, (2) mean cognitive performance for the particular task in question, and (3) exact age. Thus we were interested in whether or not age would make a significant contribution to the variance, after taking account of postural stability under single task conditions and cognitive performance under dual task conditions.

The results are summarized in Table 5. Not surprisingly, postural stability under single task conditions accounted for a significant proportion of the variance in postural stability under both dual task conditions. Cognitive performance made a further contribution in the Brooks spatial memory task [higher cognitive scores associated with lower

Table 5. Summary of Hierarchical Regression Analyses of Postural Stability for the Brooks' Spatial Memory and Backward Digit Recall Tasks

	Predicted variables [Dual SD(WD)][a]					
	Brooks' spatial memory			Backward digit recall		
	Standardized Coefficient	R-squared[c]	t[c]	Standardized Coefficient	R-squared[c]	t[c]
Predictor variables[b]						
(1) Single SD(WD)	.638	.407	4.97**	.656	.431	5.22**
(2) Cognitive performance	−.268	.071	−2.19*	−.227	.050	−1.85⁺
(3) Age	.321	.080	2.47*	.283	.066	2.22*

[a]The predicted variables are SD(WD) under each of the two dual task conditions [Dual SD(WD)].

[b]The predictor variables are (in order of entry): (1) mean SD(WD) under single task conditions [Single SD(WD)], (2) mean cognitive performance for that particular task, and (3) age.

[c]R^2 and t-values refer to the increase in variance accounted for (and associated t-value) when each predictor is added to the regression, with the previous predictor(s) already included.

⁺$p < .10$; *$p < .05$; **$p < .001$.

SD(WD)], with a similar trend in the backward digit recall task. Finally, consistent with the analyses of variance reported above, age was a significant predictor in both cases, even after controlling for the other two variables. In other words, older participants swayed even more (in comparison with younger participants) than would have been predicted on the basis of age differences in both SD(WD) under single task conditions and cognitive performance.

Are these significant contributions from age independent of intelligence (either crystallized or fluid) and information-processing speed? To address this question, we conducted further regression analyses on SD(WD) under dual task conditions for the Brooks' spatial memory and backward digit recall tasks. The predictor variables were as before [i.e., SD(WD) under single task conditions, cognitive performance and age], but with the addition of the standardized scores of crystallized intelligence (vocabulary), fluid intelligence and speed (see Table 1), making a total of six predictors. For both tasks, multiple regression analyses revealed significant effects of single SD(WD), age and speed. In other words, each of these variables accounted for significant additional amounts of variance when the other five variables were already included in the regression. For Brooks' spatial memory, the significant independent contributions were 19.2% from single SD(WD) ($t = 4.27$, $p < .001$), 7.7% from age ($t = 2.71$, $p < .05$), and 6.7% from speed ($t = -2.52$, $p < .05$). For backward digit recall, the significant independent contributions were 20.0% from single SD(WD) ($t = 4.49$, $p < .001$), 5.1% from age ($t = 2.28$, $p < .05$), and 11.0% from speed ($t = -3.33$, $p < .01$). The directions of these effects were as expected, that is, greater sway [SD(WD)] under dual task conditions was associated with: (1) greater sway under single task conditions, (2) older age, and (3) lower speed. In answer to our question, the significant contributions of age observed in Table 5 for the Brooks' spatial memory and backward digit recall tasks were unaffected by taking account of both intelligence and speed.

"Slow Drift"

The interactions in the analyses of variance tell us that age differences in postural stability were significantly larger (in fact, approximately doubled) when performing the Brooks' spatial memory and backward digit recall tasks than under single task conditions. However, it will not have escaped the reader's attention that the actual means as presented in Table 4 are rather puzzling. Thus, the interaction for Brooks' spatial memory seems to be almost as much due to a decrease in sway from single to dual task conditions for younger participants, as to an increase for older participants. For backward digit recall, the interaction seems to be more attributable to a decrease in sway from single to dual task conditions for younger participants, than to an increase for older participants.

A clue to the explanation for the unexpected pattern of single-dual differences came from viewing the plots of WD over the 30-sec runs. Our general impressions were that: (1) participants' body-weight seemed to shift slowly forward while standing up, and (2) this was more marked in some conditions than in others. These observations were confirmed by analyzing the mean of WD [Mean(WD)] rather than the standard deviation. Recall that WD is the percentage of body-weight on the scales of SwayWeigh (under the toes); this was calculated separately for the first and second halves of each 30-sec run [Mean(WD)1 and Mean(WD)2]. For 32 of the 38 participants (16 younger; 16 older), Mean(WD)2 exceeded Mean(WD)1 overall (mean difference = 1.23; $t(37) = 6.18$, $p < .0001$), consistent with the first observation.

Differences between Mean(WD)1 and Mean(WD)2 [Mean(WD)2–Mean(WD)1] were then entered into five analyses of variance, with age group as the between-subjects factor, and task condition (single vs dual) as the within-subjects factor. These revealed that Mean(WD)2–Mean(WD)1 was significantly greater under the single task condition (mean = 1.69) than under the dual task conditions of random digit generation [mean = 1.04; $F(1,36) = 4.17$, $MS_e = 1.97$, $p < .05$], and backward digit recall [mean = 0.60; $F(1,36) = 11.59$, $MS_e = 1.94$, $p < .005$], with a similar trend for Brooks' spatial memory [mean = 1.06; $F(1,36) = 3.29$, $MS_e = 2.34$, $.05 < p < .1$]. In contrast, Mean(WD)2–Mean(WD)1 did not differ between the single task condition and the dual task conditions of silent counting (mean = 1.67) and counting backward in threes (mean = 1.31). There were no main effects or interactions involving age.

It is clear that the participants' body-weight generally shifted forward during runs on SwayWeigh, perhaps as a consequence of the requirement to fixate on a point ahead. We refer to this effect as "slow drift," but obviously the above analyses do not rule out the possibility that the increase from Mean(WD)1 to Mean(WD)2 reflects several discrete movements in the anterior direction rather than one continuous movement. The point to emphasize is that an increase in WD during a 30-sec run results in an increase in SD(WD), our measure of postural stability. The average increase from Mean(WD)1 to Mean(WD)2 of 1.23 actually corresponds to an SD(WD) of 0.71 (assuming that the drift forward is linear over 30 sec), which is considerably smaller than the values observed in Table 4. This suggests that SD(WD) is much more a reflection of sway (i.e., large oscillations in WD) than of "slow drift" (i.e., gradual increase in WD over time).

The degree of "slow drift" was influenced by task condition such that participants moved forward significantly less under the dual task conditions of random digit generation and backward digit recall (and marginally less with Brooks' spatial memory) than under single task conditions. It is probably no coincidence that these were the only tasks that required participants to attend to the metronome and/or the experimenter, both of which were positioned *behind* the participant. The main point is that single-dual differences in SD(WD) have to be interpreted in light of these differences in "slow drift." For example, there was a trend toward an overall decrease in SD(WD) from single to dual task conditions with backward digit recall. But the large difference in "slow drift" between these conditions (1.69 vs 0.60) suggests that the overall result could be a combination of increased sway and decreased "slow drift" from single to dual task conditions (see below). More importantly, however, the "slow drift" effect was very similar for younger and older participants regardless of condition (overall means of 1.19 and 1.27, respectively). Thus, our main conclusions concerning age differences in postural stability across conditions are unaffected by these analyses.

Encoding vs Retrieval

Under dual task conditions with Brooks' spatial memory, participants listened during the first 15 sec of the monitoring period (encoding) and responded during the second 15 sec (retrieval). To address whether the Age × Condition interaction was due to encoding or retrieval, the postural stability data were further analyzed by calculating SD(WD) separately for the first and second halves of each 30-sec run [SD(WD)1 and SD(WD)2]. Thus, there were three factors in the analysis of variance: age, condition (single vs dual) and period (first half vs second half). As before, the effect of age was significant [$F(1,36) = 15.77$, $MS_e = 1.34$, $p < .001$], and so, too, was the interaction between age and condition [$F(1,36) = 4.56$, $MS_e = 0.47$, $p < .05$]. For younger participants, the means were 2.380 (single) and 2.372 (dual); for older participants, the means were 2.885 (single) and 3.356 (dual). This time, the effect of condition was significant [$F(1,36) = 4.28$, $MS_e = 0.47$, $p < .05$]; there was an effect of period [$F(1,36) = 8.87$, $MS_e = 0.29$, $p < .01$], and an interaction between condition and period [$F(1,36) = 25.20$, $MS_e = 0.25$, $p < .001$]. Planned comparisons indicated that SD(WD)2 was greater than SD(WD)1 under dual task conditions ($F = 34.20$, $p < .001$), but not under single task conditions ($F = 1.57$, $p > .1$). In other words, participants swayed more during retrieval than during encoding in the Brooks' spatial memory task. The crucial three-way interaction was not, however, significant ($F = 1.31$) which suggests that the Age × Condition interaction (i.e., an increased age difference in postural stability from single to dual task conditions) was similar for encoding and retrieval.

Note that there now appears to be a discrepancy between the nonsignificant increase in SD(WD) of 0.074 from single to dual task conditions in the original 2-factor analysis of Brooks' spatial memory task, and the significant increase of 0.232 from single to dual task conditions in the 3-factor analysis [SD(WD)1 vs SD(WD)2 as the additional factor]. This can be resolved by noting that when 30-sec runs are divided into two periods of 15 sec, *the effect of "slow drift" is halved*. Thus, with the addition of the third factor, the tendency for "slow drift" to decrease from single to dual task conditions is now more than counteracted by an increase in sway.

The postural stability data for backward digit recall were similarly reanalyzed, with each 30-sec run divided into two periods of 15 sec [SD(WD)1 and SD(WD)2], in order to reduce the influence of "slow drift" on the pattern of results. As in the original analysis, there was a significant effect of age [$F(1,36) = 14.48$, $MS_e = 1.40$, $p < .001$], and an interaction between age and condition [$F(1,36) = 5.67$, $MS_e = 0.33$, $p < .05$]. The effect of condition did not reach significance [$F(1,36) = 2.73$, $MS_e = 0.33$, $p = .11$], but the trend was now in the opposite direction than before. There was an overall effect of period [$F(1,36) = 4.95$, $MS_e = 0.13$, $p < .05$] such that participants were slightly less stable in the first 15 sec (mean = 2.77) than in the second 15 sec (mean = 2.65), but there were no interactions involving period (all Fs < 1). The age by condition means were as follows: 2.380 (single) and 2.311 (dual) for younger participants, and 2.885 (single) and 3.263 (dual) for older participants.

Thus, with the influence of "slow drift" effectively halved by these 3-factor analyses of variance, it becomes clear that SD(WD) increases significantly from single to dual task conditions for older participants [$t(18) = 2.46$, $p < .05$, for Brooks' spatial memory; $t(18) = 2.30$, $p < .05$, for backward digit recall], but not for younger participants [$t(18) = -0.06$ and -0.76, respectively].

Discussion

To summarize, our active healthy volunteers in their 70s and 80s were significantly less stable when standing than those in their 50s, as expected. Moreover, age differences in postural stability were significantly increased when performing two of the five cognitive tasks, namely, Brooks' spatial memory (task 2) and backward digit recall (task 3).

How does this pattern of results relate to the possibilities raised earlier? First, it does not seem to be the case that the size of the age-related impairment in cognitive performance determines the degree to which age differences in postural stability are increased. Thus, tasks 1, 2, 3, and 5 produced approximately equivalent age differences in cognitive performance (note the similar F-ratios for the main effects of age), but only tasks 2 and 3 produced larger age differences in postural stability. Second, task requirements such as externally-paced responding (shared by tasks 1 and 3) and verbal responding (shared by tasks 1, 2, 3, and 5) do not account for the results obtained. Third, with regard to the possibility of a critical working memory component, the observed pattern seems more consistent with the visuospatial sketchpad (tasks 2 and 3 — see below), than with either the central executive (required most by task 1) or the phonological loop (required most by tasks 4 and 5).

It is generally agreed that Brooks' spatial memory (task 2) requires the VSSP component of working memory (see Baddeley, 1986). As noted earlier, support for VSSP involvement in backward digit recall (task 3) comes from recent work by Li and Lewandowsky (1993, 1995) in which the authors suggested that "two very different processes underlie forward and backward recall" (Li & Lewandowsky, 1993, p. 907), and concluded that "backward recall relies on a visual-spatial representation of the study material" (Li & Lewandowsky, 1995, p. 837). This is also consistent with comments from several of our participants describing how they performed backward digit recall (task 3). Specifically, they reported "visualizing" the digits as they were presented and then "reading" off the sequence backward. Note that VSSP involvement in backward digit recall was probably encouraged in the present study by two further factors: (1) backward digit recall was performed immediately after the Brooks' spatial memory task in which participants were instructed to form a mental image of digits in a 4×4 grid, and (2) responding was externally paced, which probably discouraged alternative strategies such as subvocally rehearsing the sequence forward until reaching the final digit, peeling it off, and then repeating the process. We therefore suggest that the most parsimonious conclusion from the present pattern of results is that age differences in postural stability are increased by cognitive tasks using the VSSP component of working memory.

Clearly, the present study was limited in a number of ways. With regard to participants, these were positively selected, which may have minimized age differences. The "younger" group was middle-aged so it is possible, for example, that we failed to find an age interaction in task 1 because the central executive was already impaired in both age groups. With regard to procedure, participants were required to fixate throughout which may have been more difficult for older participants — unfortunately, we did not collect any data on visual acuity (see Lindenberger & Baltes, 1994, on the impact of age differences in sensory functioning). Postural stability was measured in the anterior-posterior plane only. There is a possibility that age differences in sway may actually be larger in the medio-lateral plane (see Teasdale et al., 1991a). Finally, the five tasks were always presented to participants in the same order. It may be significant that the only one to show a dual task decrement in terms of the cognitive data was the first to be performed (random digit generation). Participants' attention to SwayWeigh may have been greater at the beginning of the session (when the equipment and standing task requirements were novel) than later in the session.

These limitations should be addressed in future studies. However, we offer a tentative interpretation of the present results as follows: Setting up and manipulating internal visuo-spatial information (use of the VSSP) reduces the ability to use external visual information in the control of postural stability. The differential effect of performing tasks requiring the VSSP on older and younger participants can therefore be explained in the same way as others have explained the differential effect of reducing visual input (e.g., Downton, 1990; Woollacott et al., 1982). Thus, there is significant loss of proprioceptive and vestibular sensitivity in old age. Under normal conditions, vision can compensate (at least to some extent) for impaired proprioception and vestibular dysfunction. However, this is less possible under reduced visual conditions (e.g., eyes closed), with the result that older participants are more disrupted than younger participants. There was a significant contribution from age in the present regression analyses even after measures of cognitive performance, intelligence, and speed were already included in the equation. We tentatively suggest that this independent influence of age may partly reflect the physical deterioration of the proprioceptive and vestibular systems. The additional contributions from speed are of interest in view of Stelmach & Worringham's (1985) emphasis on the severe time limitations in detecting and correcting postural instability. Note that speed's contribution to the variance was greater when responding was externally paced (11.0%; backward digit recall) than when responding was not externally paced (6.7%; Brooks spatial memory).

In memory tasks, retrieval is assumed to be more attentionally demanding than encoding (Johnston, Greenberg, Fisher, & Martin, 1970; Trumbo & Milone, 1971; but see also Baddeley, Lewis, Eldridge, & Thomson, 1984). This view is supported in the present study by the finding that participants were less stable during retrieval than during encoding in the Brooks' spatial memory task. However, the interaction between age and condition (single vs dual) was not significantly different at encoding and retrieval. This provides further evidence that age differences in postural stability are increased whenever the VSSP is used, rather than whenever the overall attentional demands are increased.

The results from the Brooks' spatial memory and backward digit recall tasks provide an interesting contrast with those from the random digit generation task. There was no hint of an interaction between age and single/dual condition in either the cognitive or postural stability data for random digit generation (both $Fs < 1$). Nevertheless, there was clear evidence of dual task interference (significant in the cognitive data; masked by "slow drift" in the postural stability data). This interference between random digit generation and postural stability is consistent with the view that the central executive is important for integrating the performance of two or more concurrent tasks (see, for example, Baddeley, 1996). The absence of an interaction with age for random digit generation is also consistent with the conclusion from Baddeley, Logie, Bressi, Della Sala, and Spinler (1986) that combining two tasks does not necessarily lead to any greater decrement in the normal elderly than in the young. The picture is different, however, for patients with Alzheimer's disease who show a particular impairment in the central executive component of working memory as indicated by a greater dual task decrement (Baddeley et al., 1986). This raises the possibility that differences in postural stability between the normal elderly and Alzheimer patients may be increased by *any* attentionally demanding cognitive task.

Finally, it should be recognized that the present postural stability task was relatively easy (standing on a flat surface with eyes open, arms by the side, and feet apart). The results from a study by Stelmach et al. (1990) are of interest here. Stelmach et al. measured the postural sway of older and younger participants while they performed a cognitive task (mentally counting the number of correct addition problems presented verbally). This task had no significant effect on postural sway in either age group under normal standing conditions. However, the time required for postural sway to recover from a destabilizing period of arm-swinging was increased by the cognitive task in the elderly participants, but was unaffected by the cognitive task in the young participants. Unfortunately, the authors did not report any cognitive data, but the result raises an interesting question for future research, i.e., whether the age interactions observed in the present study would be exaggerated under more demanding or dynamic conditions of postural control than those investigated here. Clearly, it is of both theoretical and practical importance to identify the precise combinations of cognitive and postural requirements that can lead to instability and falls in the elderly.

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Appendix

Notes

1. Older participants would not be predicted to outperform younger participants on any of the cognitive tasks. We therefore report one-tailed probability levels for the main effects of age group in the analyses of the cognitive data.

2. There was an obvious outlier in the dual task data for counting backward in threes: SD(WD) for one older participant was more than three standard deviations above the mean (based on the whole sample). In fact, this was largely due to just one of the two runs which was almost four standard deviations above the mean for that particular run. For this participant, SD(WD) for the other run (which was less than two standard deviations above the mean for that run) was used, rather than the average across the two runs.