Role of motor skills and visual demand for age-related deficits in dual-task walking

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Abstract

Previous studies suggested that age-related deficits of walking are accentuated under dual-task conditions when the non-walking task is visually demanding. Here we evaluate whether a requirement for manual skills is critical as well. Young (22±2 years) and older (69±3 years) subjects walked along a straight path while performing a task that required manual skills but no visual processing, i.e., checking off boxes on a handheld panel without seeing the arm, or a task that required visual processing but no manual skill , i.e., a Stroop-like task with verbal responses. We found that the checking task affected the performance of young and elderly subjects to a similar degree, while the Stroop-like task affected seniors' performance more than that of young subjects. This outcome confirms the role of visual demand for age-related deficits of dual-task walking (in the Stroop-like task), but doesn't support a similar role for manual skills (in the checking task).

Introduction

The human gait pattern changes characteristically in advanced age. Walking speed and step duration decrease, while double-support time and the variability of step duration increase.[1-3] Changes are observed not only for temporal, but also for spatial gait parameters: lateral sway, variability of stride width and variability of leg rotation increase, while stride length and foot elevation decrease.[3-6] Some of these changes co-vary between individuals, thus suggesting a common cause; specifically, it has been hypothesized that seniors reduce their walking speed as a precautionary measure, and that the other gait characteristics change as a consequence.[6] However, not all reported changes of locomotion in old age are compensatory. The increased variability of spatial and temporal gait parameters destabilizes body posture, and correlates with the likelihood of accidental falls.[1,7] The observed gait changes therefore seem to represent a mix of deficits and countermeasures.

The degradation of walking in old age has been attributed, among others, to cognitive decay.[8] This view is supported by the fact that deficits are more pronounced in seniors with cognitive impairment[9,10] and that they can be accentuated even in healthy seniors under dual-task conditions.[11-14] The latter outcome is of practical importance: it suggests that the risk of accidental falls increases when elderly persons walk and concurrently engage in another activity, e.g., talk to a companion, watch displays in shop windows, or navigate around obstacles in their path. In order to understand the dual-task deficits in old age and to design suitable training programs, it is important to determine exactly under which conditions dual-task walking is more challenging to seniors than to younger subjects. We have therefore recently compared 14 combinations of walking and non-walking tasks, and found that dual-task interference was more pronounced in older than in young subjects when the non-walking task required ongoing visual processing, but was comparable in both age groups when the non-walking task didn't require visual processing.[3,8,15]

Our above finding fits well with earlier work. Dual-task walking was more challenging to elderly than to young subjects when the non-walking task required visual signal processing or visual imagery[12,14,16-19] but was similarly challenging to both age groups when the non-walking task required manual dexterity or auditory processing.[11,16,20-22] It therefore appears that age-related deficits are particularly pronounced when subjects must coordinate two sources of visual information, one related to walking through visually defined space,[23-25] and the other to the solution of a visual non-walking task. Since the coordination of multiple tasks is an executive function, thought to be located in the prefrontal cortex, the observed impairment could well reflect the well-known shrinkage of prefrontal cortical circuitry in old age.[26-28]

Prefrontal shrinkage and the associated decay of executive functions could affect not only the coordination of two visual tasks; executive deficits could also affect the coordination of two motor processes. Seniors might therefore experience difficulties in everyday life when they walk and concurrently perform a manual skill, e.g., reach for a handrail, operate a remote-control device, or gesticulate. In fact, one of the tasks which yielded age-related deficits in our previous work required subjects to check with a pen boxes on a sheet of paper, and thus involved not only visual processing but also manual skills. The present study was designed to separate out these two components: we designed a task that required visual processing but no manual skills, and another task that required manual skills but no visual processing.

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Materials and Methods

14 young and 14 older subjects participated; their biological characteristics are summarized in Table 1. In a self-assessment questionnaire, all subjects indicated to be free of musculoskeletal and visual impairments except for corrected refraction deficits; those who wore corrective eyeglasses upon arrival in the laboratory continued to wear them during the measurements. The questionnaire didn't explicitly ask for color perception deficits, however, such deficits seem not to degrade performance on word-color interference tasks.[29,30] The questionnaire also didn't ask for cognitive deficits: we deemed all subjects to be free of such deficits since they lived independently in the community, arrived without assistance in the correct room at the correct time, and followed our instructions properly. None of the subjects had participated in research on gait or cognition within the preceding six months. All signed an informed consent statement for this study, which was pre-approved by the authors' institutional Ethics Committee. The following

Table 1. Subjects' anthropometric characteristics (means ± standard deviations).

	Older (n=14)	Young (n=14)
Males / females	5 / 9	6 / 8
Age (years)	69.07±3.36	22.00±2.08
Height (cm)	170.43±9.69	177.21±7.69
Weight (kg)	73.43±11.14	69.71±11.38
BMI (kg/m^2)	25.16±2.20	22.43±1.60

tasks were administered twice to each subject, in a counterbalanced order: i) *walk*: subjects walked at their preferred speed along a straight pathway of 25 m length and 0.3 m width, marked on the floor by red-and-white barrier tape; ii) *check*: seated subjects held with their non-dominant hand an acrylic panel (33.0 × 25.0 cm) in which 35 rectangles (3.0 × 3.0 × 0.01 cm) were embossed in 5 columns of 7 rows. An opaque board above the panel prevented subjects from seeing the rectangles. They were asked to feel out each rectangle with the index finger of their dominant hand, mark it with an *x* using a pen in their dominant hand, and proceed as quickly as possible from the top left rectangle down, column by column, until 20 s expired; iii) $name_{comp}$: in this modified Stroop task, seated subjects held with their non-dominant hand a laminated sheet of paper (29.5 × 21.0 cm), on which the words *gelb, rot, grün* and *blau* (yellow, red, green and blue) were written in compatible color (e.g., the word *gelb* in yellow color). Subjects were asked to name the color of each word as quickly as possible, until 20s expired; iv) $name_{incomp}$: same as above, except that the meaning and color of words didn't match (e.g., the word gelb in red color). Again, subjects had to name the color of each word as quickly as possible for 20 s; v) *walk & check*: Subjects executed the tasks walk and check concurrently; vi) *walk* & $name_{comp}$: Subjects executed the tasks walk and $name_{comp}$ concurrently; vii) *walk* & $name_{incomp}$: Subjects executed the tasks walk and $name_{incomp}$ concurrently.

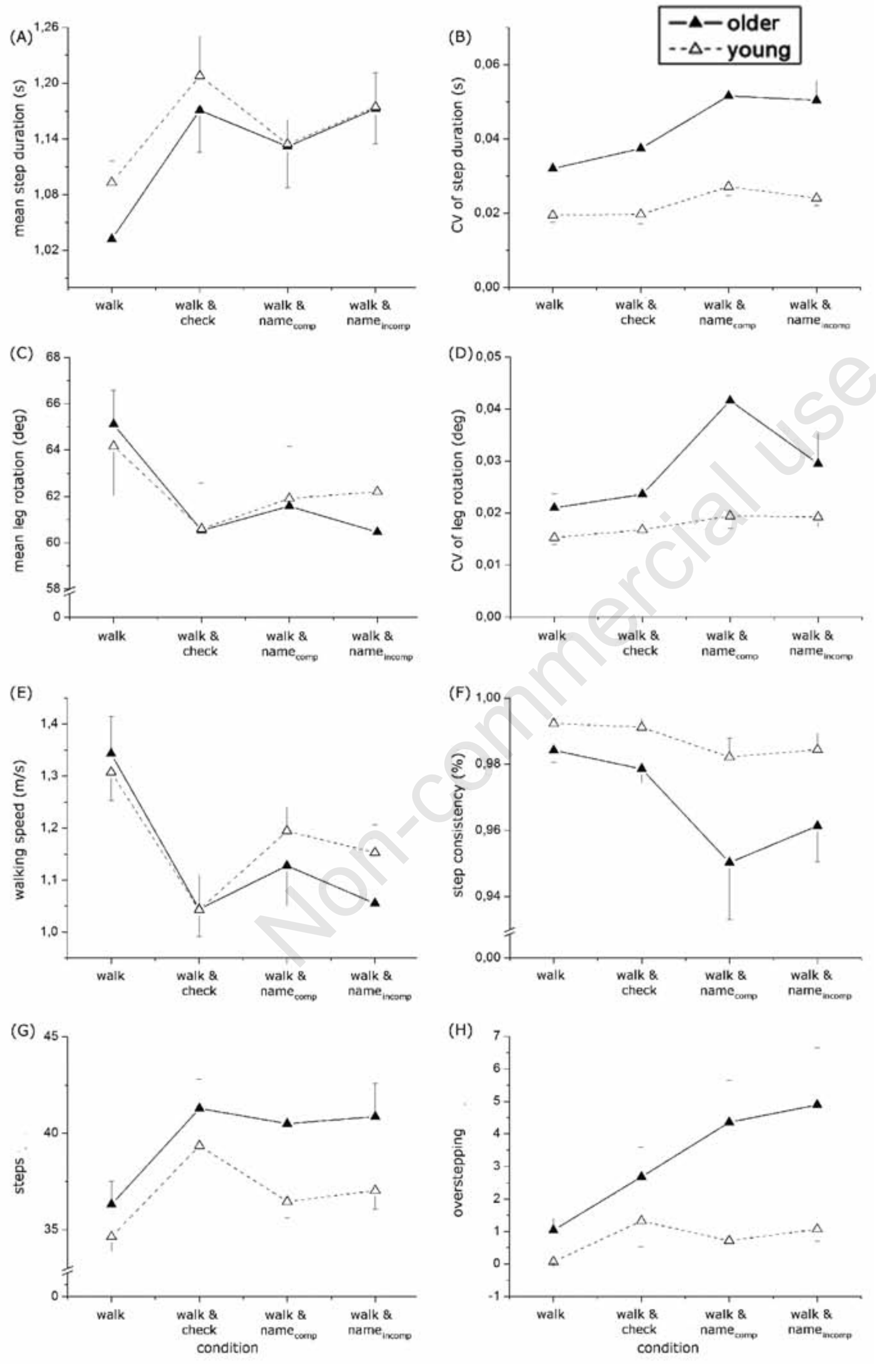

Figure 1. Eight measures of walking performance in young and older subjects under single- and dual-task conditions. Symbols represent the across-subject means of an age group, and error brackets the pertinent standard errors. CV stands for the coefficient of variation.

Locomotion was registered and analysed as in our previous work.[3,15,31] Four multisensor markers of the MTx® orientation tracking system (Xsens Technologies, NL) were affixed with Velcro strips to the upper and lower segment of the left and right leg. Sensor signals were sent by wireless transmission to a stationary computer, which extracted the orientation angle in the sagittal plane with a sampling rate of 100 Hz and an accuracy of better than 1 deg. Individual step cycles were identified offline by a recursive correlation algorithm, which determined the repetition of data segments with a similar shape.[3] We then calculated the following gait measures for each step cycle of the lower right leg: i) *step duration*: time interval between two consecutive step cycles; ii) *leg rotation*: difference between maximum and minimum leg angle within a step cycle; iii) *step consistency*: Pearson correlation between two consecutive step cycles, after normalizing for their duration and amplitude. We then calculated the means of each gait measure for each subject and task, discarding the first and last cycle of each task repetition. We also calculated the variation coefficient of *step duration* and *leg rotation*; to deconfound stochastic variability from a consistent drift, the latter calculations were based on the residuals of a quadratic fit rather than on the original scores.[3,31]

We also determined the following measures for each subject and task: i) *steps*: number of steps needed to traverse the walkway; ii) *overstepping*: number of steps outside the labeled path, as tallied by an observer; iii) *walking speed*: 25 m path length divided by walking time; iv) *checking speed*: number of checked boxes per second; v) *naming speed*: number of correctly named word colors per second.

All subjects additionally completed a battery of cognitive tests. The order of those tests was quasi-randomized, and the order of cognitive versus dual-task walking tests was counterbalanced across subjects in each age group.

Sustained alertness was assessed by the d2-test:[32] subjects were given a sheet of paper on which the letter *d* was repeatedly printed along with one, two, three or four dashes, and were asked to mark all d's accompanied by two dashes which they can identify within a given time. Their performance was scored as the number of correctly marked minus falsely marked items. *Visuo-constructive skill* was assessed by the *dice* subtest of the German intelligence test IST2000R,[33] *planning skill* by the HOTAP picture-sorting test[34] and *executive functions* by a modified Stroop test.[3] In the latter, the words *gelb* (yellow) or *grün* (green) were presented in the center of a screen in yellow or green color. Subjects were asked to respond to yellow stimuli by pressing a button with their right hand and to green stimuli by pressing a button with their left hand as quickly as possible. This instruction was fostered by the continuous display of a yellow bar along the right, and a green bar along the left edge of the screen. The color and meaning of words was congruent in one, but incongruent in another block of 55 trials. In the incongruent block, subjects had to respond in accordance with the color when a word was presented against a black background, but in accordance with the meaning when a word was presented against a gray background. For statistical analyses, we used the mean difference of reaction times in the congruent and in the incongruent block as a measure of subjects' ability to inhibit preferred responses, and to switch rules.

Each performance measure of the tasks *walk, check* and *name* was submitted to an analysis of variance (ANOVA) with the between-factor Age and the within-factor Task. Each cognitive measure was compared between age groups with t-tests. For further analyses, all walking, checking, naming and cognitive measures of elderly subjects were normalized by subtracting the pertinent mean score of young subjects. Each normalized walking, checking and naming measure was then submitted to an analysis of Co-Variance (ANCoVA) using the within-factor Task; the normalized cognitive measures served as covariates, and were added stepwise with the inclusion and exclusion criterion of P<0.05.

Results

Figure 1 displays our eight measures of the gait pattern, separately for each task and age group. It shows that already under single-task conditions, seniors produced shorter steps with higher spatio-temporal variability and with more stepping errors than young subjects. The gait changed from *walk* to *walk & check* in a similar fashion for both age groups, and age differences therefore remained essentially unaltered. In contrast, the gait changed from walk to *walk & name*$_{comp}$, and to *walk & name*$_{incomp}$, more dramatically in seniors; age differences were therefore accentuated in the

Table 2. ANOVA results - walking measures.

		Age	Condition	Age*Condition
Mean step duration	*Check*	1.15$^{n.s.}$	25.51***	0.23$^{n.s.}$
	Name$_{comp}$	0.54$^{n.s.}$	18.82***	3.25$^{n.s.}$
	Name$_{incomp}$	0.56$^{n.s.}$	29.03***	2.07$^{n.s.}$
CV of step duration	check	14.41***	0.84$^{n.s.}$	0.69$^{n.s.}$
	Name$_{incomp}$	9.49**	7.00*	1.31$^{n.s.}$
	Name$_{incomp}$	14.67***	8.77**	3.17$^{n.s.}$
Leg rotation	*Check*	0.03$^{n.s.}$	66.52***	1.01$^{n.s.}$
	Name$_{comp}$	0.01$^{n.s.}$	29.99***	1.46$^{n.s.}$
	Name$_{incomp}$	0.02$^{n.s.}$	27.38***	4.52*
CV of leg rotation	*Check*	5.15*	1.21$^{n.s.}$	0.09$^{n.s.}$
	namecomp	11.63**	8.22**	3.62$^{n.s.}$
	Name$_{incomp}$	4.05$^{n.s.}$	15.03*	0.67$^{n.s.}$
Walking speed	*Check*	0.05$^{n.s.}$	84.79***	0.32$^{n.s.}$
	Name$_{comp}$	0.30$^{n.s.}$	46.72***	4.56 *
	Name$_{incomp}$	0.14$^{n.s.}$	49.76***	4.52 *
Step consistency	*Check*	8.20 **	1.90$^{n.s.}$	0.80$^{n.s.}$
	Name$_{comp}$	3.99$^{n.s.}$	6.87*	2.01$^{n.s.}$
	Name$_{incomp}$	4.89$^{n.s.}$	8.29**	1.96$^{n.s.}$
Number of steps	*Check*	1.41$^{n.s.}$	68.17***	0.04$^{n.s.}$
	Name$_{comp}$	3.06$^{n.s.}$	29.36***	4.53*
	Name$_{incomp}$	2.86$^{n.s.}$	39.75***	3.80$^{n.s.}$
Overstepping	*Check*	2.50$^{n.s.}$	7.79**	0.14$^{n.s.}$
	Name$_{comp}$	8.26**	12.52**	5.71*
	Name$_{incomp}$	5.85*	8.30**	2.87$^{n.s.}$

Note. n.s., *, ** and ***indicate P>0.05, P <0.05, P <0.01 and P <0.001 respectively. CV, coefficient of variation; the degrees of freedom are F(1,26) for age, condition and age*condition; *check*: ANOVA results for the conditions *walk* and *walk&check*; *name*$_{comp}$: ANOVA results for the conditions *walk* and *walk&name*$_{comp}$; *name*incomp: ANOVA results for the conditions walk and walk&nameincomp.

Table 3. ANOVA results - nonwalking measures.

	Age	Condition	Age*Condition
Checking speed	1.85$^{n.s.}$	35.87***	1.34$^{n.s.}$
Naming speed$_{comp}$	36.94***	37.08***	2.88$^{n.s.}$
Naming speedin$_{comp}$	30.36 ***	2.72$^{n.s.}$	1.15$^{n.s.}$

Note. n.s., *, ** and ***indicate P >0.05, P<0.05, P <0.01 and P <0.001 respectively. The degrees of freedom are F(1,25) for age, condition and age*condition.

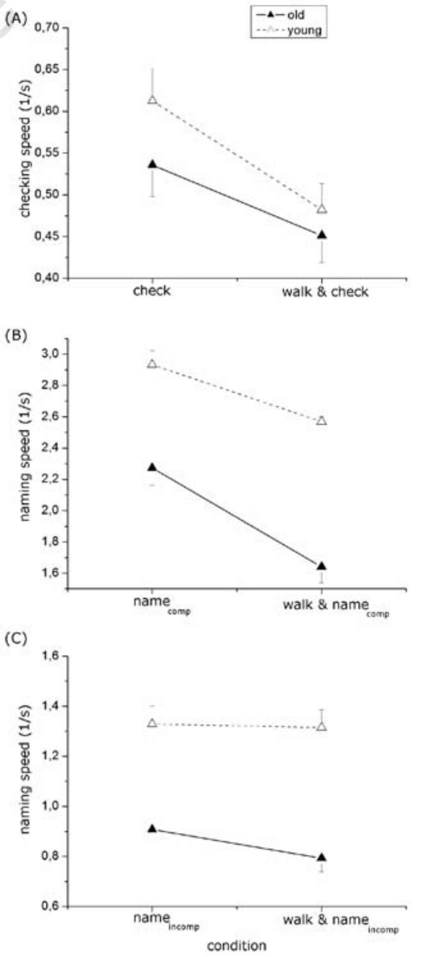

Figure 2. Performance measures for the three non-walking tasks in young and older subjects under single- and dual-task conditions. Symbols represent the across-subject means of an age group, and error brackets the pertinent standard errors.

latter two conditions. Figure 2 depicts the corresponding data from the three non-walking tasks: again, older subjects preformed less well than young ones already under single-task conditions, and were more affected by concurrent walking on task walk & $name_{comp}$ and walk & $name_{incomp}$, but not on task *check*.

Table 2 summarizes the ANOVA outcome of our walking measures: in accordance with the above observations, the Age*Task interaction was significant for several measures when walking was combined with naming, but not when it was combined with checking. Table 3 presents the corresponding analyses of checking and naming: the interaction term didn't reach significance for those tasks.

Young subjects outperformed older ones on all four cognitive tests, alertness (t(26)=-7.43; P<.001), *visuo-constructive skill* (t(26) = -3.72; P<0.001), *planning* (t(26)=-5.16; P<.001) and *executive functions* (t(26)=-4.05; P<.001). Linear regressions analyses yielded no significant correlations between *alertness* and *visuo-contructive skill* (R^2=0.014; P>0.05), alertness and planning (R^2=0.03; P>0.05) or *alertness and executive function* (R^2=0.009; P>0.05).

Stepwise ANCoVAs of seniors' normalized walking measures yielded significance for only one co-variate: *alertness* had significant effects on walking speed (F(1,12)=9.74; P<.01), on the number of steps (F(1,12)=8.55; P<.05) and on the variation coefficient of leg rotation (F(1,12)=5.71; P<.05). The effect of Task was not significant in those three ANCoVAs (all P>0.05), but it became significant when the co-variates were removed and the analyses run as ANOVAs with the single factor Task. Stepwise ANCoVAs of seniors' normalized naming and checking measures yielded no significant co-variates for *check,* but significant effects of alertness (F(1,11)=7.88; p<0.05) and *visuo-constructive skill* (F(1,11)=9.13; P<0.05) for $name_{comp}$, and of alertness (F(1,12)=7.93; P<0.05) for $name_{incomp}$. Again, the effect of Task was not significant in those ANCoVAs (all P>0.05), but it became significant when the co-variates were removed. Thus, the majority of dual-task deficits in our elderly subjects were accounted for by their reduced alertness level.

Discussion

The present study investigated the conditions under which age-related deficits of dual-task walking emerge. Having shown that such deficits mainly manifest with non-walking tasks that require substantial visual processing,[3,8,15] we now scrutinized whether the need for manual skills is critical as well. To this end, we designed task check which calls for precise hand movements but not for visual processing, as well as tasks $name_{comp}$ and $name_{incomp}$ which call for visual processing, a varying degree of cognitive processing, but not for hand movements.

Our data confirm earlier findings that the spatio-temporal structure of locomotion changes in old age.[3,4,8,11,35] More importantly, the age difference didn't increase noticeably when the task *check* was added; thus, the need to evaluate tactile and proprioceptive information from the hand, and to program precise finger movements, seems not to produce age-related walking deficits beyond those already present under single-task conditions. Likewise, the age difference on task *check* didn't increase when subjects concurrently walked. We thus found no evidence for age-related dual-task deficits under *walk & check*, and can't substantiate the view (see Introduction) that seniors may have problems to coordinate locomotion with manual skills. In contrast to task check, adding task $name_{comp}$ or $name_{incomp}$ actually did increase the age differences in several gait measures, which confirms our earlier finding that dual-task deficits emerge when the non-walking task is visually demanding.[8,36] This age-related increase manifested on temporal as well as spatial gait measures, thus confirming and expanding our previous observation – based merely on a temporal measure - that cognitive demand is not a main determinant of age-related deficits.[8,36]

Elderly subjects performed less well than younger ones on all four cognitive tests administered in the present study, but alertness was the only cognitive measure that co-varied with age-related deficits of dual-task walking, and in fact, fully accounted for several of those deficits. It therefore appears that the ability to walk and concurrently engage in another visual task is impaired because of seniors' problems to stay focused and alert, and not because of a decay of the executive functions tested by our modified Stroop task, i.e., decision-making, inhibition and rule switching. This does not necessarily imply that the dual-task impairment is completely independent of prefrontal shrinkage and the associated decay of executive functions;[26-28] rather, it could depend on executive abilities not specifically addressed by our Stroop task, such as multitasking, spatially selective attention, planning and monitoring of own actions, and anticipation of outcomes. It is conceivable that those abilities depend on a sustained level of alertness, and were thus indirectly gauged by the d2 test of alertness. However, seniors exhibit deficits even if the visual non-walking task is only brief,[15] and problems of sustained alertness therefore can't explain all their problems of dual-task walking.

Alternatively or additionally, dual-task walking could be degraded in old age because of impaired processing of complex visual information. Indeed, visual working memory,[37,38] the functional field of view[39,40] and exploratory eye movements[41-43] are all degraded in the elderly. Yet another interpretation holds that seniors rely for walking increasingly on foot vision,[44,45] which is typically blocked by visual non-walking task; however, this view is in conflict with the observation that seniors' deficits persist even if the visual non-walking task doesn't interfere with foot vision.[3]

Summing up, the present data confirm that seniors have difficulties to walk and concurrently engage in a visually demanding task, but not in a task that requires manual skills without vision. It remains conceivable that difficulties are aggravated when tasks requiring vision also require manual skills, since previous work using such tasks reported deficits on more gait measures and of a larger magnitude than the present study.[3,8,36] Future fall prevention programs should take the critical role of visual demand into account, and include training components such as walking while catching a ball or while reading a billboard.

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