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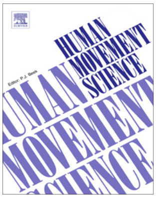

Does the walking task matter? Influence of different walking conditions on dual-task performances in young and older persons

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Previous literature suggests that age-related deficits of dual-task walking are particularly pronounced with second tasks that require continuous visual processing. Here we evaluate whether the difficulty of the walking task matters as well. To this end, participants were asked to walk along a straight pathway of 20 m length in four different walking conditions: (a) wide path and preferred pace; (b) narrow path and preferred pace, (c) wide path and fast pace, (d) obstacled wide path and preferred pace. Each condition was performed concurrently with a task requiring visual processing or fine motor control, and all tasks were also performed alone which allowed us to calculate the dual-task costs (DTC). Results showed that the age-related increase of DTC is substantially larger with the visually demanding than with the motor-demanding task, more so when walking on a narrow or obstacled path. We attribute these observations to the fact that visual scanning of the environment becomes more crucial when walking in difficult terrains: the higher visual demand of those conditions accentuates the age-related deficits in coordinating them with a visual non-walking task.

1. Introduction

The gait pattern of older people is affected by fundamental changes with advancing age. For example, stride-time, stride-time variability as well as double-support time increase while walk-

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0167-9457 © 2013 The Authors. Published by Elsevier B.V. Open access under CC BY license.
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ing speed, step-length and step-height decrease (Beurskens & Bock, 2011; Bock, Engelhard, Guardiera, Allmer, & Kleinert, 2008; Hollman, Kovash, Kubik, & Linbo, 2007; Schrager, Kelly, Price, Ferrucci, & Shumway-Cook, 2008). Some of the observed changes are compensatory mechanisms to stabilize body posture and allow safe locomotion; some of them co-vary between individuals indicating a common cause. Older people primarily reduce their walking speed as a precautionary measure and other gait measures change (e.g., stride-time increases, step length decreases) as a consequence thereof (Winter, Patla, Frank, & Walt, 1990). Many studies describe changes in gait behavior as impairments that are correlated with a higher risk of accidental falls (Hausdorff, Rios, & Edelberg, 2001; Maki, 1997). Therefore, the observed gait changes seem to illustrate a mixture of deficits and countermeasures that affect temporal measures as well as spatial ones.

The changes of walking capabilities in older age have been attributed, among others, to a decrease in cognitive capabilities (Bock, 2008), potentially caused by an age-related shrinkage of prefrontal grey matter and the associated decline of executive functions (McDowd & Shaw, 2000; Raz et al., 1997). Indeed, the crucial role of cognition for elderly walking is supported by the circumstance that age-related changes are more pronounced in persons with cognitive detriments (Hausdorff, Edelberg, Mitchell, Goldberger, & Wei, 1997; Holtzer, Verghese, Xue, & Lipton, 2006) and can be emphasized even in healthy seniors when walking in dual-task conditions (Li, Lindenberger, Freund, & Baltes, 2001; Lindenberger, Marsiske, & Baltes, 2000; Lundin-Olsson, Nyberg, & Gustafson, 1997). The latter note is of practical importance for older peoples' everyday life. It suggests that the risk of falling increases when a person is engaged in walking and concurrently handling another activity, e.g., watch street signs or navigate around a crowded environment.

A recent review showed that the amount of deficits that occur while dual-task walking depends on the demands that a secondary task creates (Beurskens & Bock, 2012). Dual-task interferences seem to be more pronounced in older than in young subjects when the non-walking task requires continuous visual processing, but is similar in both age groups when the non-walking task does not require the processing of visual information (Beurskens & Bock, 2011; Bock & Beurskens, 2011a, 2011b). Especially, in dual-task walking, subjects have to coordinate two sources of visual information, one related to navigating through visually defined spaces (Imai, Moore, Raphan, & Cohen, 2001; Nomura, Mulavara, Richards, Brady, & Bloomberg, 2005), and the other to the solution of a visual non-walking task (Beurskens & Bock, 2011). This kind of information processing is similar to everyday demands where different visual inputs have to be coordinated, e.g., while walking in a crowded mall or along a street while watching for street signs. One aspect that has attracted little attention in recent dual-task walking studies is the role of different walking tasks and their demands for dual-task walking. Only a few studies evaluated the influence of different terrains (Gates, Wilken, Scott, Sinitski, & Dingwell, 2012; Marigold & Patla, 2008) or the presentation of obstacles (Chen et al., 1996; Patla & Vickers, 1997) on human locomotion and found that even young participants contacted the floor with a flatter foot and with an increased knee and hip flexion when walking on variable surfaces (Gates et al., 2012). Furthermore, the role of visual information and the processing thereof becomes more crucial when obstacles have to be avoided (Patla & Greig, 2006; Patla & Vickers, 1997) or when walking over different surfaces (Marigold & Patla, 2008). For example, older people contact more obstacles when vision is perturbed (Menant, St George, Sandery, Fitzpatrick, & Lord, 2009), but unfortunately the latter study did not include young adults for control to distinguish age-related differences, which is a methodological constraint of several recent studies (Hawkes, Siu, Silsupadol, & Woollacott, 2012; Hegeman et al., 2012).

Despite these facts, the role of visual processing for human dual-task walking in different walking terrains is largely unknown. Therefore, the presented study tries to answer the questions (1) how different walking task difficulties influence dual-task performance in young and older individuals and (2) whether this impact of different locomotor task difficulties differ between visually dominated versus non-visual secondary tasks? To find out, participants were asked to walk either at normal speed, at a fast pace, on a narrow path, or to avoid obstacles presented in their path.

2. Methods

2.1. Subjects

15 young and 15 older subjects participated in this study; their biological characteristics are summarized in Table 1. All subjects lived independently in the community and had not participated in research on dual-task locomotion or cognition within the preceding 6 months. All participants had normal or corrected-to-normal eye vision and reported to be free of orthopedic and muscular impairment in a questionnaire completed before participating in the actual study. Since all participants arrived without help at the agreed-upon time in the agreed-upon place, properly followed our instructions, and correctly completed questionnaire items requiring memory and orientation (e.g., address, date of birth, medication used), we deemed them to be free of gross cognitive impairment as this kind of questionnaire is equivalent to the demands of the short mental status examination (MMSE) that is widely used in literature (Lajoie, Teasdale, Bard, & Fleury, 1996; U'Ren, Riddle, Lezak, & Bennington-Davis, 1990). Before participating, all signed an informed consent statement for this study, which was preapproved by the authors' institutional Ethics Committee.

2.2. Experimental procedure

2.2.1. Single-tasks

Participants were asked to walk along a straight pathway of 20 m length in four different conditions that represent common situations in everyday life:

- *wide:* walking at their preferred speed along a straight pathway of 1.8 m width
- *narrow:* walking along a straight pathway of 0.3 m width marked on the floor with red and white tape. Participants were instructed to walk at their preferred speed, and not to overstep the marked path.
- *obstacle:* walking along a straight pathway of 1.8 m width. In irregular distances three obstacles of 2 cm height and 8 cm depth and two obstacles of 10 cm height and 8 cm depth were placed along the way. Participants were instructed to walk at their preferred speed and to step over the obstacles without touching them.
- *fast:* walking at fast pace along a straight pathway of 1.8 m width. Participants were instructed to walk as fast as possible without running.

Non-walking single tasks were chosen based on previous studies showing age-related differences when performing these task concurrently while walking (Bock, 2008; Bock & Beurskens, 2011a). Task *check* calls for continuous visual processing: it would be impossible to perform it with eyes closed. In contrast, task *button* can easily be performed with eyes closed, even though occasional glimpses may be beneficial for performance. For simplicity, we will call task *button* "non-visual".

- *check:* seated participants held a sheet of paper (21.0 × 29.5 cm) in their non-dominant hand on which 65 squares (1.0 × 0.8 cm) were drawn in 5 columns of 13 rows. They were instructed to check each box as quickly as possible by an "X", using a pen in their dominant hand; they were to start with the top left box, and proceed from top to bottom, column by column, until 20 s expired (Bock & Beurskens, 2011a). We ensured by inspection that the location and orientation of the sheet

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

Males/females	Older (n = 15) 4/11	Young (n = 15) 8/7
Age (years)	70.5 ± 6.4	21.7 ± 1.2
Height (cm)	170.2 ± 9.7	175.0 ± 7.4
Weight (kg)	69.4 ± 12.9	69.2 ± 9.7
BMI (kg/m^2)	23.7 ± 2.3	22.4 ± 1.6

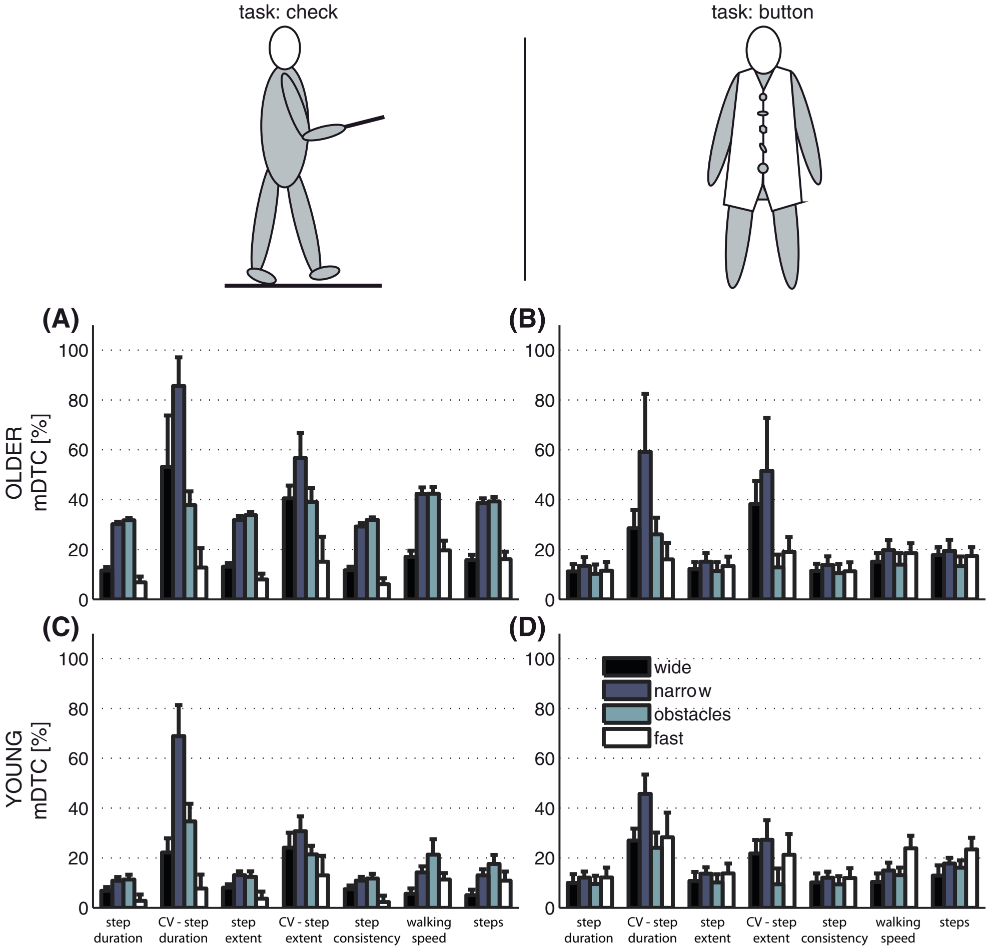

Fig. 1. Presentation of mean dual-task costs (mDTC) separated for older subjects (displayed in the middle part, A+B) and young subjects (displayed in the bottom part, C+D) in four different walking conditions and two task combinations. (A) represents older subjects in task: check, (B) older subjects in task: button, (C) young subjects in task: check and (D) young subjects in task: button. Bars display the across-subject means for each age group and walking condition and error brackets the pertinent standard errors. Older subjects are most effected by narrow and obstacle walking in (A) but not in (B). mDTC are lesser for young in both, (C) and (D). The top part of Fig. 1 shows schematic drawings of condition *check* (left side) and condition *button* (right side).

was comparable for each individual subject during single- and dual-task checking. A schematic drawing of condition “*check*” is shown in the top left part of Fig. 1.

- *button:* seated participants wore a jacket with five buttons affixed on the front from top to bottom. All buttons differed in shape and size. Participants were asked to fasten up the jacket from top to bottom as quickly as possible until 20 s expired. When all five buttons were closed during the 20 s period, participants started opening the buttons again from bottom to top. A schematic drawing of condition “*button*” is shown in the top right part of Fig. 1.

2.2.2. Dual-tasks

- *wide & check:* Participants executed the tasks “*wide*” and “*check*” concurrently.
- *narrow & check:* Participants executed the tasks “*narrow*” and “*check*” concurrently.

- *obstacles & check:* Participants executed the tasks "*obstacle*" and "*check*" concurrently.
- *fast & check:* Participants executed the tasks "*fast*" and "*check*" concurrently.
- *wide & button:* Participants executed the tasks "*wide*" and "*button*" concurrently.
- *narrow & button:* Participants executed the tasks "*narrow*" and "*button*" concurrently.
- *obstacles & button:* Participants executed the tasks "*obstacle*" and "*button*" concurrently.
- *fast & button:* Participants executed the tasks "*fast*" and "*button*" concurrently.

The 14 different tasks and task combinations were administered twice to each subject, in a randomized order to prevent any order effects. In order to prevent participants from prioritizing one or the other task during dual-task conditions, we did not instruct them beforehand. We only told them what walking condition was used and what this condition required (e.g., staying between the markings on the floor during condition "*narrow*" or walking as fast as possible without running during condition "*fast*").

2.3. Data registration

Participants' walking performance was registered with the MTx® orientation tracking system (Xsens Technologies B.V., Enschede, NL). The system consists of 4 sensors tracking orientation angles in the sagittal, frontal and transversal plane that were attached to the thigh and shank via Velcro strips (Beurskens & Bock, 2011; Bock & Beurskens, 2010, 2011b). Online recorded data was sent by Bluetooth transmission to a stationary laptop which identified the orientation angle in the sagittal plane with a sampling rate of 100 Hz and an accuracy of <1 deg. Individual step cycles were identified in the orientation-angle signal by a recursive sliding-correlation algorithm. A template segment of 390 ms duration was selected and its correlations with consecutively shifted 390 ms segments were calculated. The first shifted segment for which the correlation reached a maximum was taken as the onset of a new step cycle. The shifted segment was then selected as a new template and shifted until the correlation peaked again, etc. A human operator supervised the algorithm and could modify its outcome, which was rarely necessary (cf. Fig. 1 in Bock & Beurskens, 2011a). We then calculated the following gait measures for each step cycle of the lower right leg:

- *step duration:* time interval between two consecutive step cycles
- *step extent:* difference between maximum and minimum leg angle within a step cycle
- *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 participant and task, discarding the first and last cycle of each task repetition to prevent an influence of de- and acceleration on our means. Due to the walking conditions the number of steps varied between 22 and 32 steps, averaging 28 steps to traverse the 20 m walkway. Hence, a minimum of 20 and a maximum of 30 steps were used for data analysis. We also calculated the variation coefficient of *step duration* and *step extent*.

Additionally, we determined the following measures for each participant and task:

- *steps:* number of steps needed to traverse the walkway
- *walking speed:* 20 m path length divided by walking time
- *checking speed:* number of checked boxes per second
- *buttoning speed:* number of fixed buttons per second

To quantify subjects' ability for executing two tasks concurrently, we calculated the dual-task costs (DTC) for each participant, task combination and performance measure, according to the common formula (McDowd, 1986): $\mathrm{DTC} = \frac{(\mathrm{D}-\mathrm{S})}{\mathrm{S}}$, where 'D' represents the score of a measure under dual-task conditions, and 'S' the score of the same measure under single-task conditions. For example, D could be the step duration of a subject in *wide & check*, and then S was the step duration of the same subject in *wide*. Or, D could be the checking speed of a subject in *wide & check*, and then S was the checking speed of the same subject in *check*. We then calculated the mean dual-task costs for each participant, task combination and performance measure as:

$$\mathrm{mDTC} = \frac{\mathrm{DTC_{walking}} + \mathrm{DTC_{non-walking}}}{2}.$$

For example, $\mathrm{DTC_{walking}}$ could be the DTC for step duration of a subject in *wide & check*, and then $\mathrm{DTC_{non\text{-}walking}}$ was the DTC for checking speed of the same subject in *wide & check*. mDTC are commonly calculated in dual-task literature to de-confound dual-task ability from task prioritization: When a person gives high priority to walking, her DTC may only be substantial on the non-walking task, and when another person gives high priority to the non-walking task, her DTC may only substantiate on walking; mDTC is not sensitive to such differences between subjects.

2.4. Cognition

Recent studies have shown that subjects' levels of cognitive performance co-varied with deficits of dual-task walking in the elderly (Beurskens & Bock, 2011; Bock & Beurskens, 2011a, 2011b). Therefore, all participants additionally completed two cognitive tests that were accomplished after 50% of the walking and non-walking tasks were completed (i.e., after 7 tasks) to ease the demands of our 14 walking tasks. Participants' *planning skill* was measured by the HOTAP picture-sorting test (Menzel-Begemann, 2009) and *executive functions* were measured by a modified Stroop test (Bock & Beurskens, 2011a). In the former, participants had to chronologically arrange pictures of everyday situations (e.g., shopping in a supermarket or refuel a car at a gas station) that were presented in a wrong order. Every correctly rearranged picture resulted in one point. For statistical analysis, we calculated the combination score according to the following calculation: total amount of points divided by processing time. In the latter test, the words 'gelb' (yellow) or 'grün' (green) were presented in the center of a screen in yellow or green color. Participants 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, participants 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.

2.5. Data analyses

To avoid separate analyses of each walking measure – and the associated loss of statistical power – we decided to use multivariate analyses of variance (MANOVAs) and covariance (MANCoVAs), with the between-factor age, the within-factors walking condition (wide, narrow, obstacle, fast) and walking Parameter (i.e., mDTC of each walking measure) and with the covariates *planning ability* and *executive-function*. The analyses were done separately for buttoning and for checking, and covariates were added stepwise with the inclusion and exclusion criterion of $p < .05$. We used the Wilks' lambda multivariate statistic to determine the significance of our results, and Fisher's LSD tests for post-hoc testing. As an alternative to MANOVA, we also calculated the average of all seven walking measures for check and for button, separately for each age group and gait condition, and submitted the outcome to an analysis of variance (ANOVA) with the between-factor age and the within-factor condition. Furthermore, each cognitive measure was compared between age groups with *t*-tests.

3. Results

Fig. 1A–D shows the mDTC of our seven walking measures for each task and each age group separately. It points out that in task check the mDTC for every walking measure, regardless of their

Table 2
MANOVA outcomes for the tasks "check" and "button".

(A) task: check	
Age	$F(1,28) = 30.72$ ***
Condition	$F(3,26) = 29.15$ ***
Age*Condition	$F(3,26) = 3.45$ **
Parameter	$F(6,23) = 17.95$ ***
Age*Parameter	$F(6,23) = 1.36$ n.s.
Condition*Parameter	$F(18,11) = 4.46$**
Age*Condition*Parameter	$F(18,11) = 1.88$ n.s.
(B) task: button	
Age	$F(1,28) = 0.24$ n.s.
Condition	$F(3,26) = 3.03$*
Age*Condition	$F(3,26) = 1.42$ n.s.
Parameter	$F(6,23) = 11.06$***
Age*Parameter	$F(6,23) = 1.28$ n.s.
Condition*Parameter	$F(18,11) = 2.09$ n.s.
Age*Condition*Parameter	$F(18,11) = 0.68$ n.s.

Note: n.s., *, ** and ***indicate $p > 0.05$, $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively.

temporal or spatial characteristic, were higher in the older group compared to young participants. Also, the increase in gait conditions *narrow* and *obstacle* is more pronounced in the elderly (Fisher LSD post-hoc: both $p < .001$) and mDTC were higher than in gait conditions *wide* and *fast* (*Fisher LSD* post-hoc: both $p > .05$). In contrast, task *button* did not show an age-related increase of mDTC for any of the presented walking measures. The presence or absence of mDTCs in task button is related to our four gait conditions and to the individual walking measures, but not to age. However, the manifestation of an in- or decrease of mDTC in the latter condition is rather inconsistent for both age groups. Therefore, age-related differences in mDTC seem to be more accentuated when combining walking with a visual checking task than when combining walking with a non-visual buttoning task. Table 2A summarizes the MANOVA outcome of our walking measures for task check and Table 2B shows the MANOVA outcomes for task button. In accordance with the above observation, the effects of age, condition and Age × Condition were significant for task check and only the effect of condition was significant for task button. One might argue that the above analyses confounded the effects of age with those of gender, since the gender distribution of our young and older subject group was not identical (cf. Table 1). We therefore replicated the above analyses after randomly discarding four young males and four older females, thus using four males and seven females per age group. The significance pattern remained the same for task *button* and for task *check* inspite of the smaller group size, with two minor exceptions: The effect of Age × Condition in task *check*, which reached a *p*-value of .004 in our original analysis (see Table 2), now became less significant ($p = .03$) and the effect of Condition in task button increased significance from $p = .02$ in our original analysis to $p = .009$ in the gender-matched analyses.

For further analysis, we calculated the means of all seven walking measures for task check and for task button separately for each group and each gait condition to give a general overview of the effect of task on our walking measures. These *overall DTC* are presented in Fig. 2. Again, the analysis showed an age-related increase in overall DTC for the different gait conditions. For task check, ANOVA yielded effects of age ($F(1,28) = 30.72$, $p = .000$), condition ($F(3,84 = 38.69$, $p = .000$) and Age × Condition ($F(3,84 = 4.66$, $p = .004$). In condition narrow and obstacle the overall DTC are more pronounced in the older group than in young subjects. In the remaining conditions wide and fast, the differences between age groups are rather small. For task button, only an effect of condition can be obtained ($F(3,84 = 3.65$, $p = .02$). Age ($F(1,28) = 0.26$, $p = .62$) and the interaction of Age × Condition ($F(3,84 = 1.09$, $p = .36$) did not reach significance.

Young participants outperformed older ones on both cognitive tests, planning ($t(28) = -9.98$, $p = .000$) and executive functions ($t(28) = -4.13$, $p = .000$). Stepwise MANCoVAs of mDTC measures yielded no significance for any of the cognitive co-variates in any of the two task conditions. In our

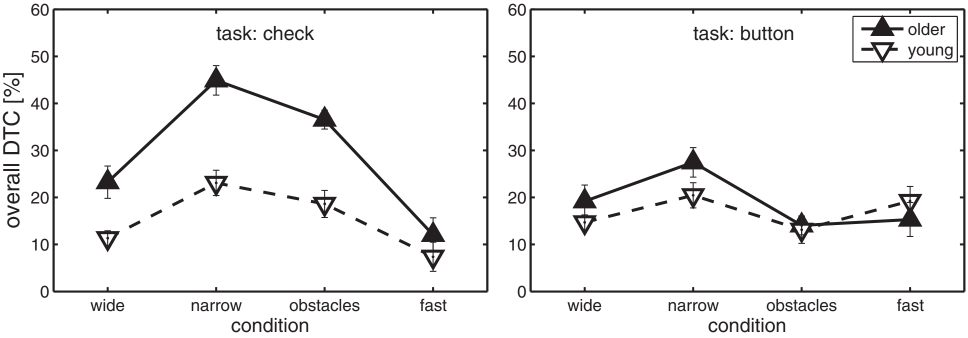

Fig. 2. Presentation of subjects' overall dual-task (overall DTC) performance separated for young and older subjects in four different walking conditions. Symbols represent the across-subject means of an age group, error brackets show the pertinent standard errors.

task check, planning reached, $F(1,27) = 0.05$, $p = .83$, and executive functions attained, $F(1,27) = 2.25$, $p = .15$. Similar results can be shown for task button. Planning skills resulted in $F(1,27) = 0.03$, $p = .87$, and executive function achieved $F(1,27) = 3.74$, $p > .06$.

4. Discussion

The present study was designed to investigate the role of differently challenging walking conditions and their demands on the human sensory and cognitive system on age-related deficits in dual-task walking. Having shown that age-related deficits mainly manifest with non-walking tasks that require substantial visual processing (Beurskens & Bock, 2011; Bock & Beurskens, 2010, 2011b), we now scrutinized whether the need to control walking in different environments is critical as well. To this end, we combined four walking tasks with task check – which depends heavily on visual processing – and with, task button – which depends little on visual processing. We attempted to use walking scenarios that occur in real life as well. Stepping over an obstacle or walking at a fast pace may be required in everyday life, for example when stepping up or down a curbstone or speeding up when being late for an appointment or when someone needs to catch a bus.

Our results are consistent with previous findings that the temporal and the spatial structure of human locomotion is affected by older age (Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008; Hollman et al., 2007; Krampe, Schaefer, Lindenberger, & Baltes, 2011; Priest, Salamon, & Hollman, 2008). Here we could show that these changes in older peoples' gait pattern is more pronounced when a visually demanding task, which in this study is the task *check*, needs to be controlled while walking (Beurskens & Bock, 2011; Bock & Beurskens, 2010, 2011a, 2011b; Li et al., 2001; Lindenberger et al., 2000). When combining two tasks with the need for visual processing, older subjects have to coordinate two sources of visual information, one related to navigating through visually defined environments (Imai et al., 2001; Nomura et al., 2005), and the other to the solution of a visual non-walking task (Beurskens & Bock, 2011). This task combination seems to exceed older participants' cognitive capabilities. In contrast, the need to process tactile and sensory feedback from the hand and fingers in order to generate adequate finger movements to handle the buttons does not seem to be challenging enough to produce age-related walking deficits. It has to be noted that in task check the MANOVA yielded a significant effect for the factor Parameter which indicates that our results depend on the walking measures itself. Age-related changes in measures of tempo-spatial variability and walking speed seem to be more accentuated than changes in mean spatio-temoral measures. This outcome indicates that different aspects of performance show a different sensitivity to dual-task interference. This outcome confirms earlier works that found age-related impairments in dual-task walking most prominent in measures of gait variability (Dubost et al., 2008; Hausdorff et al., 1997, 2001; Springer et al., 2006) and that considered a decrease in walking speed as the main effect and other gait measures change as a consequence thereof (Winter et al., 1990).

More importantly and despite the evaluation of secondary task demands on dual-task walking, this study focused on the question whether the difficulty of the walking task has an impact on age-related changes in dual-task performance. Bock (2008) stated that age-related changes in dual-task walking mainly depend on the secondary task but do not change when walking in different conditions. The present outcome partly contradicts this assumption and shows that the occurrence of age-related changes in human locomotion in combination with secondary tasks seems to depend on the additional task demands as well as on the demands of walking in various conditions and the challenges of different walking tasks. Especially, older people walking on a narrow path or avoiding obstacles in their path are more affected when combining walking with a visual demanding task than older people walking at a fast pace or at their preferred walking speed in a wide hallway. Even young participants are influenced by these task combinations and reduce their walking speed and increase their temporal and spatial variability, but these changes are more strongly linked to older age (Beurskens & Bock, 2012; Bock & Beurskens, 2011b). One can argue that this outcome is fostered by an obstruction of participants' lower field of view but this assumption contradicts former findings that found dual-task performance in young and older individuals to be independent from their ability to see their feet (Bock & Beurskens, 2011a). The present study confirms research on obstacle avoidance behavior in older people. Older adults in single-task condition cross obstacles with a reduced step velocity while using smaller step length and width compared to young adults and thus using a smaller base of support (Chen et al., 1996; Lowrey, Watson, & Vallis, 2007; Weerdesteyn, Nienhuis, & Duysens, 2005). The presented results extent research on obstacle negotiation in the elderly by showing that age-related changes are more accentuated when avoiding obstacles and concurrently processing a visual demanding task and further show a decrease in dual-task performance when walking on a narrow path. The role of visual information while walking plays a crucial role in human walking, especially when walking over varying terrain (Marigold, 2006) or negotiating obstacles (Patla & Greig, 2006) which can explain our findings that deficits occur with a visual demanding task but are absent with a sensory task without demands to the human visual system. Also, different gaze behavior in young and older adults may contribute to different dual-task walking behavior. In a collision avoidance task, older adults fixate the floor more often even in undisturbed walking environments while young adults only show this behavior in challenging walking situations (Paquette & Vallis, 2010).

Although our elderly participants scored less well on both cognitive tests, those of executive functions and planning, their cognitive performance had no explanatory value for the presence or absence of age-related changes of dual-task walking in our four walking conditions. Recent studies have shown that especially subjects' level of alertness co-varied with deficits of dual-task walking in the elderly (Beurskens & Bock, 2011). This relationship might be relevant for this study as well. Assuming that participants switched visual attention back and forth between walking and checking rather than integrating two streams of visual information concurrently, the checking task becomes more of a switching task. Task switching involves contributions of both, executive functions and attention. We did not test for attentional processes in our cognitive battery and therefore cannot state whether age-related attentional deficits influenced participants' dual-task performance in this study. But the fact that we did not find correlations between cognitive functions and motor performance in this study does not mean that cognitive functions are irrelevant for dual-task walking. Especially, executive functions have been proven to influence older peoples dual-task performance (Bock & Beurskens, 2011b) and the absence of correlations in this study might be explained by the assumption that the changes of dual-task walking found in this study depend on executive abilities that were not specifically addressed by our cognitive tests, such as multi-tasking, spatially selective attention, monitoring of own actions and anticipation of outcomes. It is conceivable that those abilities depend on a sustained level of alertness.

Summing up, the present data are in line with previous research and confirm that older adults have difficulties to walk and simultaneously engage in a visually demanding task, and extend this knowledge to the observation that these difficulties are even more pronounced when walking in demanding situations. It remains open, to what extent cognitive functions explain changes in this context as our results are not in line with previous findings on the role of higher level cognitive functions for dual-task walking.

Authors' contributions

Both authors have read and concur with the content of the final manuscript. The material within has not been and will not be submitted for publication elsewhere except as an abstract. Both authors have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

Conflict of interest

The authors declare that there is no conflict of interest associated with this work.

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