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The interacting effects of treadmill walking and different types of visuospatial cognitive task: Discriminating dual task and age effects

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ABSTRACT

Objective: The objective of this study is to examine the influence that visuospatial cognitive tasks have on gait function during DT treadmill walking, and as a function of age. Conversely, to examine the influence that walking has on executive functions involving visuospatial processing.

Methods: Twenty-five young (26 ± 6.1 years) and 25 older adults (76 ± 3.9) performed different types of computerized visuomotor (VM) tracking and visuospatial cognitive tasks (VCG) while standing and treadmill walking. Spatiotemporal gait variables, average values and co-efficient of variation (COV) were obtained from 40 consecutive steps during single- and dual-task walk trials. Performance-based measures of the VM and VCG task were obtained during standing and walking.

Results: VM dual-task walking had a significant effect on gait measures in the young age group (YG), but no DT effect was observed in the old age group (OG). Visuomotor tracking performance, however, was significantly reduced in the OG as compared to the YG when tested in both standing and walking. The opposite was true for VCG; a significant DT effect on gait performance was observed in the OG, but no DT effect was observed in the YG. Success rate of the VCG task decreased during walking, but only for OG.

Conclusion: Controlling gait speed and objective evaluation of the visuospatial cognitive tasks helps to determine the level of engagement in the DT tasks. This is important in order to determine the strategies used during the DT test protocols, i.e. cross-domain interference.

1. Introduction

Safe, independent community walking requires both mobility skills and cognitive flexibility to attend to a range of environmental demands, for navigation, to identify and track visual targets, reading, talking, etc. Mobility and cognitive abilities are closely linked, and it is now well established that dual-task walking results in significant gait changes, and dual-tasking poses a bigger challenge among older adults (Muir, Gopaul, & Montero Odasso, 2012). Unfortunately, both mobility skills and cognition are often affected as we grow older. For example, gait variability, specifically stride time variability increases during dual-tasking in older as well as cognitively impaired individuals, and may be a sensitive predictor of falls in older adults (Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010; IJmker & Lamoth, 2012; Springer et al.,

2006). Recent studies provide evidence that older adults who simultaneously perform physical and cognitive training experience greater improvements in executive cognitive functioning, compared to those performing cognitive training alone (Gregory et al., 2016; Pichierri, Wolf, Murer, & de Bruin, 2011).

Most DT gait studies performed over ground show a decreased walking speed, thus; there is a planned strategy to reduce the physical demands or threat to balance. Reduced gait speed is commonly observed in many older adults and a slowing of gait speed is also observed when negotiating obstacles and irregular terrains, (i.e. perceived threats to balance). Many DT gait studies examine how information processing load affects gait rhythm or stability, (i.e. spatiotemporal gait variables or analysis of trunk linear acceleration) (Asai, Doi, Hirata, & Ando, 2013). However, gait speed is a confounding variable,

as spatiotemporal gait variables and trunk motion are sensitive to changes in gait speed (Keene, Moe-Nilssen, & Lamb, 2016). Most over ground DT walking studies use an instrumented walkway, which records only 4–6 consecutive steps (Weir, 2005). This method, may reliably measure gait speed, but is not sufficient for measures of gait rhythm or variability, particularly during dual-task walking (Al-Yahya et al., 2011; Beurskens and Bock, 2012; Lexell and Downham, 2005). Furthermore, there is a limited choice of executive cognitive tasks that can be completed and assessed during the short time period of a few seconds to walk a few meters. A majority of DT assessment paradigms has utilized general cognitive tasks, such as; walking while talking, verbal fluency, serial subtraction (3′s or 7′s) or auditory Stroop. These do not involve visuospatial processing, and are limited in what individual brain areas are recruited (Al-Yahya, Dawes, Smith, Dennis, Howells, & Cockburn, 2011; Beurskens & Bock, 2012). Processing of visual spatial orientation cues and object locations are important aspects of community ambulation (Logan et al., 2010 Nagamatsu, Liu-Ambrose, Carolan, & Handy, 2009). To overcome these limitations, Szturm and colleagues developed and validated a computer game-based treadmill platform (CGP) (Szturm, Sakhalkar, Boreskie, Marotta, Wu, & Kanitkar, 2015; Szturm et al., 2013; Szturm, Reimer, & Hochman, 2015). It consists of a treadmill instrumented with a pressure mat (Vista medical Ltd, Winnipeg, CA) to measure spatiotemporal gait variables during walking and a commercial motion detecting computer Mouse, (Elite Gyration® Air Mouse®, www.gyration.com, California, USA). The motion mouse is a miniature and wireless plug-n-play computer interface device, which allows physical motion to be translated and interpreted as a standard USB mouse, and with high fidelity and responsiveness. The miniature motion mouse is attached to a plastic head band, and therefore, hand-free, head rotation is used to control the motion of the computer cursor or game sprite. In this manner the participant can interact with many different visuospatial computer activities while treadmill walking.

With this method both spatiotemporal gait variables and performance of the visuospatial cognitive task can be quantified, and during walk trials of over 30–40 consecutive steps.

1.1. Study purpose and hypothesis

The purpose of the present study was to examine the influence that visuospatial cognitive tasks have on gait performance during dual-task treadmill walking conditions in young adults as compared to older adults, and vice-a-versa to examine the influence that physical demands have on visuospatial cognitive performance. Participants walked on a treadmill at a fixed speed 0.7 m/s while viewing a computer monitor and interacting with different types of standardized visuomotor and visuospatial cognitive tasks. This study addressed three primary hypotheses, which are as follows;

a.) Increased visuospatial cognitive loads (single to DT walking) will have a significant effect on gait performance measures in both older and young adults.
b.) The Dual-task cost of the gait performance measures will be significantly greater for older adults as compared to younger adults.
c.) Increased physical demands (walking versus standing) will have a greater influence on visuospatial cognitive task performance measures in older adults than they will in younger adults.

Improved methods of screening and assessment of gait function to identify mobility limitations and fall risk in older adults could prevent injuries and related costs.

2. Materials and methods

2.1. Participants

Two groups of adults volunteered to participate in this study. One group included 25 older adults, (14 females, mean age 76 ($^{+/-}$ 3.9) years) who attended the Reh-Fit Centre in Winnipeg, MB for recreational exercise. They were living independently in the community and were able to walk outside for distances greater than 400 m and without any walking aids. All participants reported at least one fall in the past year and had MMSE score greater than 25. Exclusion criteria includes participants with a) diagnosis of stroke, traumatic brain injury or other neurological disorders such as Parkinson's disease or a peripheral Vestibular disorder, b) cardiac patients who did not receive clearance from their physician to take part, c) musculoskeletal injuries or orthopedic diseases such as acute neck, lower back or lower extremity pain, advanced hip/knee arthritis, d) uncorrected vision deficit (i.e. unable to clearly see the computer display). The second group included, 25 active young adults, (9 females, mean age 26 ($^{+/-}$ 6.1) years) were recruited from the student community at the University of Manitoba, Canada and participated in fitness and sports activities on a regular basis. Volunteers were screened for any exclusion criteria; history of neurological or musculoskeletal injuries.

Prior to testing, each participant from the old age group completed a 6-min walk test (6MWT) on a 300-m track, and the average walking speed was determined over the first 25-m see Table 1. The study was approved by the University of Manitoba, Human Research Ethics Committee HREB 2014:330 and participants provided informed consent prior to participation.

2.2. Computer game tasks

A custom computer application, with the following two assessment modules was used for this study (Szturm et al., 2013; Szturm, Sakhalkar, Boreskie, Marotta, Wu, & Kanitkar, 2015; Szturm, Reimer, & Hochman, 2015):

1. Visuomotor (VM) Tasks: The goal is to align two moving objects. One object (circle) is computer controlled and moved horizontally (left-right) or vertically (up-down) on a computer display for 45 s (22 cycles) at a predetermined frequency (0.5 Hz) and amplitude (70% of monitor width/height). The second object (square) is slaved to head rotation using a head-mounted motion sense mouse (Alhasani et al., 2015; Szturm et al., 2013; Szturm, Reimer, & Hochman, 2015). The goal of the task is to maintain an overlap of the two objects for 45 s. The computer application generates a logged data file to record the coordinates of the circle (target) and square (head rotation) at 100 Hz. The data file is processed off-line to quantify visuomotor performance as described below. Participants were tested in two directions; a) horizontal motion (left/right) and b) vertical motion (nose-up/nose-down).

Table 1
Demographics along with baseline physical activity levels and cognitive status.

	Demographics	
	Old n = 25	Young n = 25
Age	76 (3.9)	26 (6.1)
Male: Female	11:14	16:09
Gait speed	1.0 m/s	x
6MWT	602 m	x
MMSE	29 (0.44)	x
TMT-part A	45.1 ± 3.98 s	x
TMT-part B	118.81 ± 10.86 s	x

(x) Was not assessed in the young group.

2. Visuospatial Cognitive Game (VCG) tasks: The goal was to move a paddle (the game sprite) to interact with moving game objects. Head rotation via the motion sense mouse was used to move the game paddle and catch the target objects while avoiding distractor objects. The target object was a brightly colored circle and the distractor object was another colored cylinder, which changed color with each game event. The software presents moving target objects appearing at random locations at the top or right edge of the monitor, and move to opposite edge in a time period of 1.5 s. For each game event (target appearance) the participant moves the paddle to catch the target. Each game was played for 60 s or 45 game events. Half of the movements were in each direction. Two game levels were used; a) Target plus one distractor with the game objects moving left to right in a straight horizontal trajectory (VCG-H) and b) Target plus one distractor with a diagonal movement trajectory (VCG-D). The software indexes the "times" for the appearance and disappearance of each target game object and logs the position coordinates of the game objects and paddle (participant's head rotation) at a sampling rate of 100 Hz.

2.3. Testing

Walking trials were conducted on a standard treadmill (Sports Art Fitness Ltd) which was instrumented with a pressure sensor mat (Vista Medicals Ltd, Winnipeg). The vertical force of each foot contact was recorded, and subsequently used to compute center of foot pressure (COP) displacement (Alhasani et al., 2015; Betker, Maharjan, Yaduvanshi, Szturm, & Moussavi, 2008). Fig. 1 illustrates the experimental set-up.

11 All testing was done in a controlled lab-based environment over one visit, which lasted for one hour. Participants stood on the treadmill at a viewing distance of 100 cm from an 80 cm wide LED computer monitor. The testing protocol was demonstrated to the participants, and they were given practice when standing to become familiar with the VM and VCG computer task. Participants walked on the treadmill for five minutes for acclimation before testing was initiated. The single task, walk only (WO) condition was performed first for 1 min. The VM and VCG tasks were then performed in standing. This was followed by treadmill walking while performing the VM and the VCG tasks. The VM tasks were performed for 45 s and the VCG tasks were performed for 60 s. Rest periods of 1–2 min between tasks were given to all participants

The treadmill walking tasks were difficult when performing the concurrent game tasks, particularly for the old age group. The treadmill was equipped with safety side rails within easy reach and participants were fitted with a safety harness secured above to a support system. In addition, during all tests, a physical therapist stood behind the participants to provide assistance if required.

2.4. Data processing

Spatiotemporal gait variables: Fig. 1. Illustrates the method of extracting the gait variables from recorded COP signals of the instrumented treadmill. Average and Co-efficient of Variation (COV) was quantified from the 30 consecutive steps of the VM tasks and from the 45 consecutive steps of the VCG tasks. The average and (COV) of the following gait variables were determined for right and left sides; Step length (SL), Stride time (ST), Swing time (SwT), and Single support times (SsT). Statistical analysis (paired t-test) demonstrated no significant difference in the group means of right and left gait variables, and therefore, only the right side gait variables are reported in the analysis. In addition, Dual-task cost (DTC) was computed for all gait variables (average and COV) using the formula; DTC [%] = 100 * (single-task score – dual-task score)/single-task score (Alhasani et al., 2015). A higher dual task cost signifies a decline and or worsening in performance during the dual task test as compared to the single task.

Visuomotor Performance: Fig. 2. Presents synchronous plots of the target motion (circle) and user's head rotation (square) for a typical visuomotor task. The Total Residual Error (TRE) was determined by computing the difference between the trajectories of the target and head cursor motions. Secondly, the movement amplitudes for each direction, (i.e. max to min and min to max positions) were computed for each one-half movement cycle. Amplitude Variability, a measure of movement consistency over 20 cycles was then determined as standard deviation normalized by mean for all the cycles over 45 s. Statistical analysis (paired t-test) demonstrated no significant difference in amplitude variability for right-left direction or up-down directions, and therefore, amplitude consistency of one direction (right and up) are reported in the analysis. The first two cycles of the visuomotor tracking tasks were excluded to allow the participants' time to acquire the moving target and begin tracking.

Visuospatial Cognitive Performance Measures: In Fig. 3 Panel A, the following variables, averaged over all upward game movements were determined; a) success rate determined as the percentage of target objects that were caught, b) average movement time; i.e., the time from target appearance to the start of the game paddle (head rotation) and c) movement variance. Panel B, presents overlay trajectories of individual head pointing movements for all game events in one game session. Based on time indices of target appearance and disappearance, the software segments multiple movement traces for each direction. Each movement trace (game event) is from target appearance (time zero) to target disappearance (1.5 s). Panel C, the software then sorts these movement traces by direction and for medium amplitude movements. Thus, the software produces multiple, standardized contextual movement events (Players actions) for each direction. For a detailed description of the game movement indexing and segmentation for details see Szturm, Sakhalkar, Boreskie, Marotta, Wu, and Kanitkar (2015) and Lockery, Peters, Ramanna, Shay, and Szturm (2011)). The individual movement traces for each direction in one game session were averaged and the standard deviation computed for each sampled data point. The average standard deviation over all sampled data points was taken as movement variation. MATLAB (The Math Works, Natick, MA, version 2010a) was used to compute all outcome measures described above.

2.5. Statistical analysis

Descriptive statistics, including means, standard deviation, frequencies, and percentages, were used to describe demographic variables. Normality of our data was assessed using the Shapiro-Wilks test (n < 50). This test revealed a non-normal distribution p < 0.01 for the majority of gait performance measures variables (average and COV). In addition, Mauchly's test of sphericity, which was used to test the equality of variance for comparison between different task conditions, was also violated p < 0.01. Hence, non-parametric procedures were used to test our hypotheses. Between group comparison of gait and visuospatial cognitive performance measures obtained during single task conditions were conducted using a Mann-Whitney test or an Independent Sample T-test (Gibbons & Chakraborti, 2011)

To test our first hypothesis, we conducted a Freidman's ANOVA for each age group to determine the effect of task conditions (single versus DT) on gait variables (average and COV). A post hoc pair wise comparison with Bonferroni correction was conducted for significant findings using the Wilcoxon signed rank test (WSRT) (Gibbons & Chakraborti, 2011). To test the second hypothesis, a Mann-Whitney test was conducted to examine the effect of age on dual task cost for the gait variables (average and COV).

The VM and VCG performance measures satisfied the assumptions of normality and equal variance. Hence, statistical analysis was conducted using parametric tests. For our final hypothesis, to examine the effects of physical demands (standing vs treadmill walking) and age on VM and VCG performance measures a Two-way repeated measures ANOVA was used. A post hoc pairwise comparison was conducted for

A. Experimental set-up

B. Pressure mat recording during walking
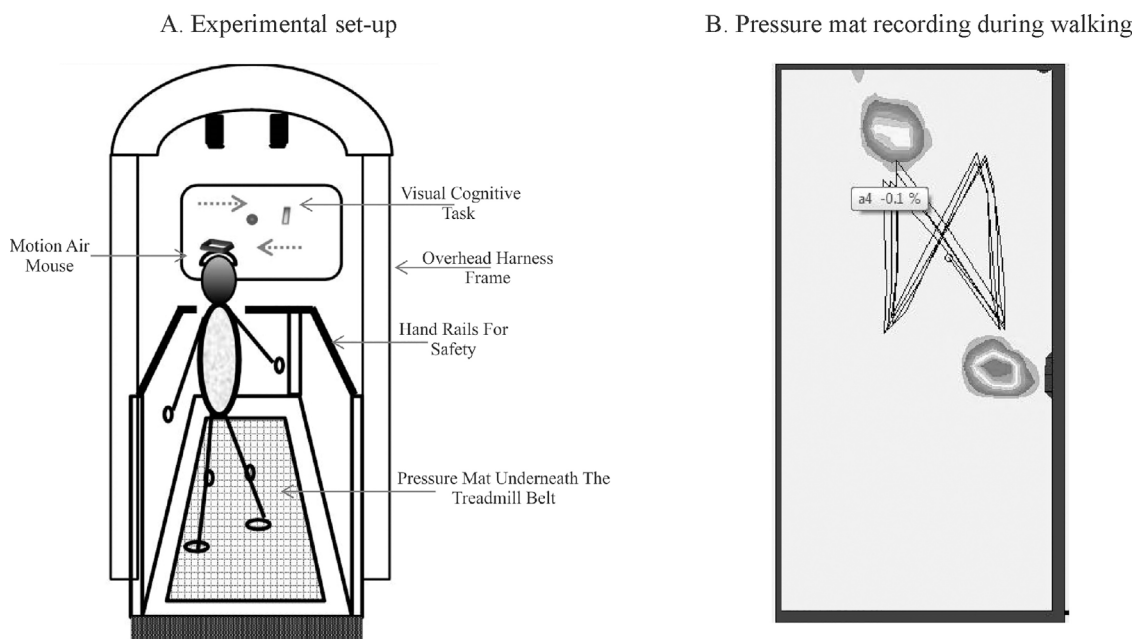
C. Center of foot pressure (COP) displacement in AP and ML direction for 3 steps.
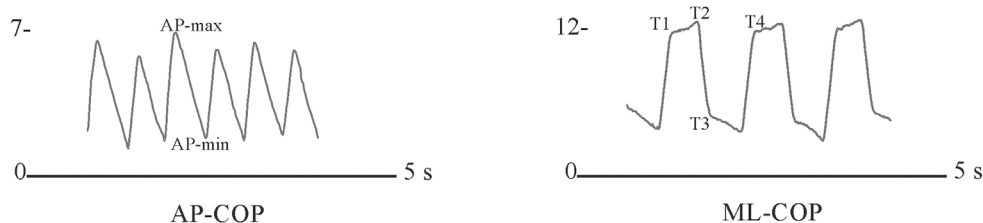
Gait variables extracted from AP & ML COP signal

AP-max-AP-min = Right Step Length (cm)
T2-T1 = Right Single Support Time (s)
T3-T2 = Right Swing Time (s)
T4-T1 = Stride Time (s)

Fig. 1. Panel A Experimental set-up. Participant is shown walking on treadmill while viewing a computer monitor and using head rotation (motion mouse) to interact with visuospatial cognitive task. Panel B presents snapshot of left and right foot-ground vertical force profiles obtained during walking. Panel C presents AP and ML COP times series data for 3 steps. Maxima and minima AP-COP excursion points for right and left steps are quantified, and use to compute swing and step times and step length. Start and end of plateau phases of ML-COP are quantified for right (upper plateaus) and left lower plateaus). Single support times are then computed.

significant findings using the T- test (Girden, 1992).

The significance level was $\alpha = 0.05$. All statistical analysis was conducted using SPSS (Version 22 for Windows, SPSS Science, and Chicago, IL).

3. Results

Eight out of the 25 older participants could not perform the VM dual-task without holding onto the treadmill hand rails. Therefore, the sample size of the old age group was 17 for VM dual-task and 25 for the VCG dual-task.

The group medians and interquartile range (IQR) of gait performance measures for WO are presented in Fig. 4 (average values) and Fig. 5 (COV values). For all average gait measures, old age group showed significantly lower; ST, ($z = 2.3$, $p < 0.05$), SwT, ($z = 2.1$, $p < 0.05$), and SsT, ($z = 2.5$, $p < 0.01$), as compared to the young age group. In addition, COV for all gait measures was almost twice in old age group SL, ($z = 3.2$, $p < 0.01$), ST, ($z = 3.3$, $p < 0.01$), SwT, ($z = 3.1$, $p < 0.01$), and SsT, ($z = 3.2$, $p < 0.01$).

The group means and standard error of means (SEM) for the visuomotor performance measures are presented in Fig. 6A. Total residual error ($t_{49} = 9.5$, $p < 0.01$) and Amplitude Variability ($t_{49} = 7.7$, $p < 0.01$) was significantly greater in old age group compared to young age group. As presented in Fig. 6B the VCG performance measures when tested in standing were significantly poor in the old age group as compared to the young age group; average movement time was significantly greater, ($t_{49} = 6.2$, $p < 0.01$) and Success Rate was significantly lower, ($t_{49} = 2.2$, $p < 0.05$) in the old age group as compared to the young age group. No age effect was observed for Movement variation.
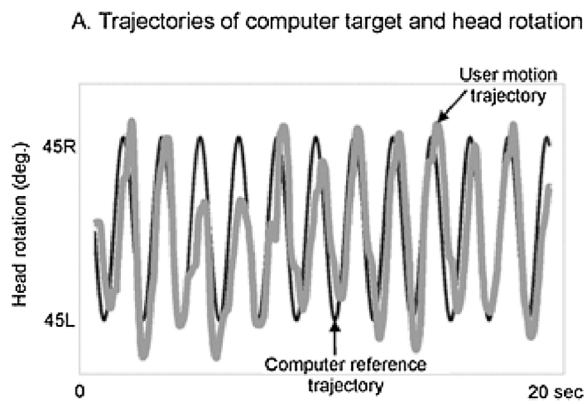
A. Trajectories of computer target and head rotation

Fig. 2. Present synchronous plots of the reference cursor motion and user movement trajectories (head rotations) for visuomotor tracking task. Maxima are left most position and minima right most position.

3.1. Dual-task effects on gait performance measures

Statistical results (Friedman ANOVA) of the effect of the VM dual-tasks on gait performance measures are presented in Table 2. The group medians and Inter-quartile ranges for the gait measures are presented in Fig. 4 (average) and Fig. 5 (COV). There was a significant increase in COV for SL and ST when performing the VM tasks as compared to WO in the young age group, but no effect of the VM dual-task on COV was observed in the old age group for any gait variables. The VM dual-task also resulted in a significant decrease of Avg-SL in the young age group. Post hoc pairwise comparison (Wilcoxon test) showed a significant increase from walk alone to walk plus VM-H for COV of SL ($z = 6.4$, $p = 0.03$), ST ($z = 6.1$, $p = 0.03$), and SwT ($z = 5.6$, $p = 0.04$) in the young age group. A significant increase was also observed from walk alone to walk plus VM-V in the young age group for COV of SL ($z = 5.5$, $p = 0.04$), ST ($z = 5.3$, $p = 0.04$), and SwT ($z = 6.2$, $p = 0.03$).

Statistical results (Friedman ANOVA) of effect of the VCG dual-tasks on the gait variables are presented in Table 2. The group medians and interquartile ranges for the gait variables are presented in Fig. 4 (average) and Fig. 5 (COV). Results of the effect of the VCG dual-tasks on gait performance measures for the most part are opposite as those seen for VM dual-tasks. There was a significant increase in COV of ST, SwT, and SsT when performing the VCG tasks as compared to WO in the old age group, but no dual-task effect was observed in the young age group. The VCG dual-task had a significant effect on all average gait variables; SL, ST, SwT, and SsT in the old age group, and only on the Avg-ST in the young age group. Post hoc pairwise comparisons (Wilcoxon test) showed a significant decline from walk alone to walk plus VCG-D of all average gait variables; SL ($z = 7.3$, $p = 0.001$), ST ($z = 6.6$, $p = 0.007$), SwT ($z = 5.2$, $p = 0.01$), and SsT ($z = 5.4$, $p = 0.01$) in the older age group. A significant decline from walk alone to walk plus VCG-H was also observed in the old age group for ST ($z = 4.78$, $p = 0.018$), SwT ($z = 4.7$, $p = 0.02$), and SsT ($z = 5.35$, $p = 0.01$). There was a significant increase from walk alone to walk plus VCG-D for COV' of all temporal gait variables, ST ($z = 3.9$, $p = 0.03$), SwT ($z = 4.8$, $p = 0.02$), and SsT ($z = 5.3$, $p = 0.01$)) in the older age group. No significant increase in gait variation was observed in the old age group when performing the VCG-H tasks

A between group analysis for age effect on DTC was not conducted, since only one age group showed a significant dual-task effect for either VM or VCG.

3.2. Dual-task effects on the visuomotor performance measures

Statistical results of the two-way repeated measure ANOVA are presented in Table 3, and group means and standard error of mean (SEM) are presented in Fig. 6. Physical demands (standing versus
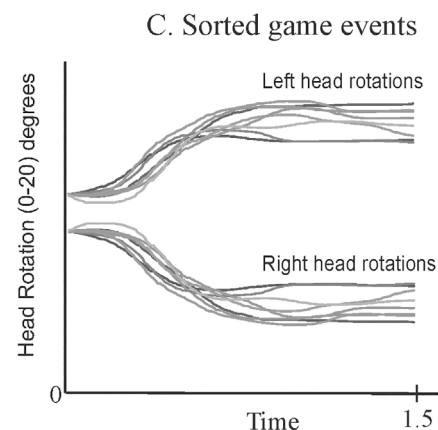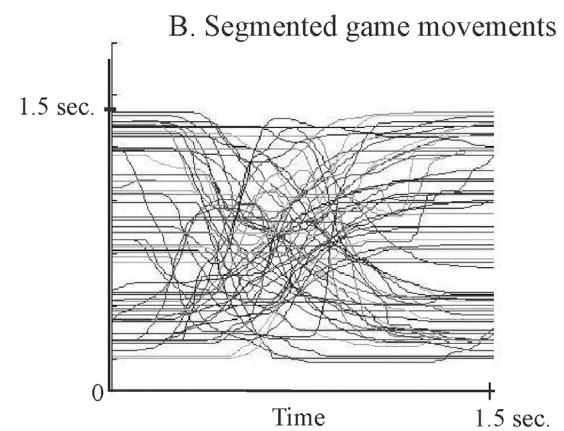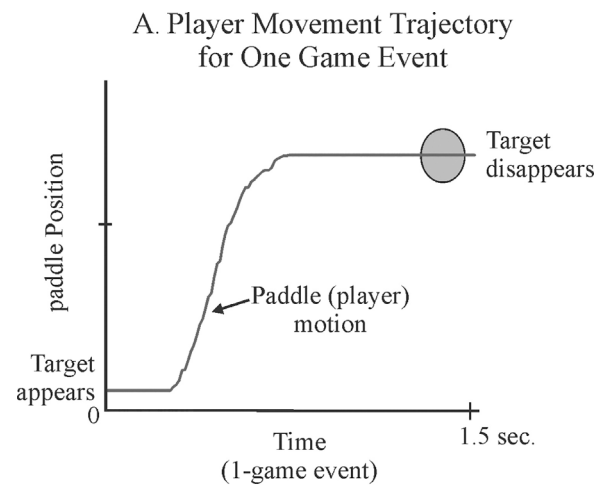
A. Player Movement Trajectory for One Game Event

B. Segmented game movements

C. Sorted game events

Fig. 3. Panel A Presents the movement trajectory for one game event from target appearance to target disappearance. Further, following outcome measures are extracted from each game event, which is for 1.5 s; a) success rate determined as the percentage of target objects that were caught, b) average movement time; i.e., the time from target appearance to the start of the game paddle (head rotation) and c) movement variance. Panel B presents trajectory of game paddle movements (head rotation) for one logged game file, 60 s duration. Each game event is 1.5 s in length; thus, recording includes an average of 30 game events. As presented some game movements are upward and some downward (i.e. different movement directions) and some game movements were medium or large amplitude. In addition, for each game event the location of the target appearance is random and direction and amplitudes of the player's movements (head rotation) are randomized. Panel C segmented game events are sorted grouped in functional bins, which in this case represent medium amplitude player movements in leftward direction (upward trajectories), and rightward direction (downward trajectories). Also, illustrates analysis methods to quantify response time and movement time from grouping of leftward, medium amplitude game events of one trial.
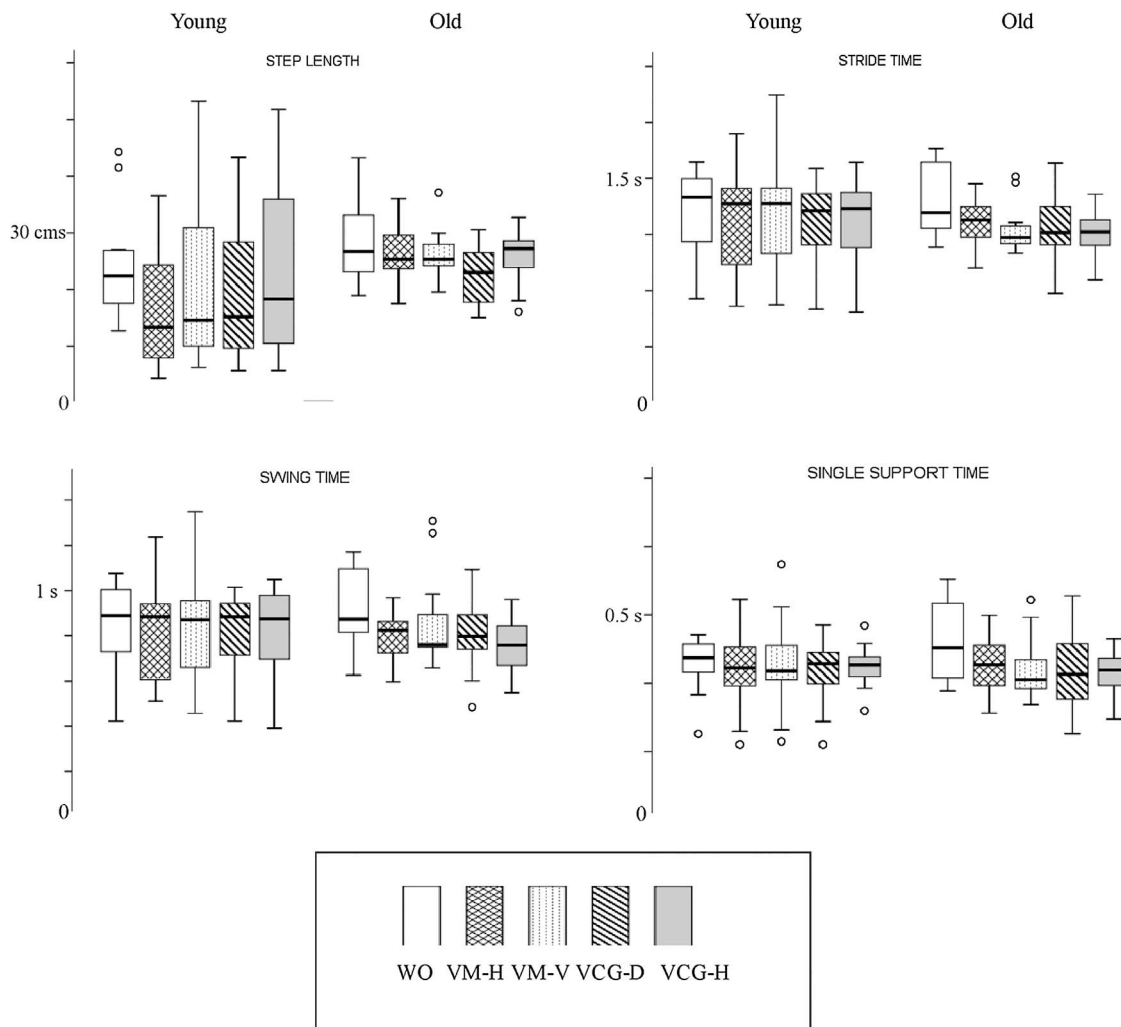
Fig. 4. Present box-plots, each box-plot represents the group medians and inter-quartile ranges (IQR) for different task conditions for the average gait variables; a) Step Length b) Stride Time c) Swing time, and d) Single support time in young and old age groups.

treadmill walking) had a significant main effect on VM Total residual error (TRE) and on Amplitude Variability. A significant age effect was observed for Amplitude Variability, but not for TRE. Post hoc pairwise comparison (Tukey's test) showed an increase in TRE from standing to walking in the young age group ($t_{16} = 2.5$, $p = 0.017$), but no change was observed in the old age group ($t_{16} = 0.17$, $p = 0.86$). Amplitude Variability increased from standing to walking in both the young, ($t_{16} = 1.8$, $p = 0.05$) and the old age group ($t_{16} = 3$, $p = 0.008$).

3.3. Dual-task effects on the visuospatial cognitive outcome measures

Statistical results of the Two-way repeated measures ANOVA are presented in Table 3 and the group means (SEM) are presented in Fig. 6. Physical demands (standing versus treadmill walking) had a significant main effect on the Response Time and Success Rate, but not on Movement Variation. No significant age effect was observed for any of the VCG performance measures. Post hoc pairwise comparison (Tukey's test), showed a significant increase in Response Time from standing to walking in the young age group ($t_{24} = 1.7$, $p = 0.04$), but no significant change in Response Time was seen in the old age group ($t_{24} = 0.7$, $p = 0.4$). Whereas Success Rate significantly declined from standing to walking in the old age group, ($t_{24} = 1.3$, $p = 0.05$) when performing the VCG tasks, but no significant change in Success Rate was seen in the young age group ($t_{24} = 0.07$, $p = 0.9$).

4. Discussion

The purpose of the present study was, to examine the interaction between physical and visuospatial cognitive loads as a function of age using the dual-task paradigm. The addition of visuomotor tasks during treadmill walking had a significant negative effect on gait performance in the young age group but no effect was observed in the old age group. The opposite was observed for the VCG tasks, the dual-task trials had a significant negative effect on gait performance in the old age group but no DT effect was observed in the young age group. Cognitive performance, success rate for the VCG tasks decreased during dual-task walking, but only in the old age group, whereas, Response Time for VCG task increased during DT walking only in the young age group.

Analysis of the walk alone trials showed that the old age group walked with shorter steps and swing durations, as compared to the young age group. In addition, the old age group exhibited significantly greater gait variability (twice that of the young age group). These findings are in agreement with previous results by Verghese et al. (2006), Bridenbaugh and Kressig (2014), and Gilles, Verghese, and Beauchet (2016). Increased gait variability in older adults is indicative of reduced gait stability and associated with increased fall risk (Hausdorff, Rios, & Edelberg, 2001; Yogev-Seligmann et al., 2010).

When tested in standingsingle task) VM performance measures were significantly reduced in the old age group as compared to the young age group; TRE was three times greater and Amplitude Variability was two
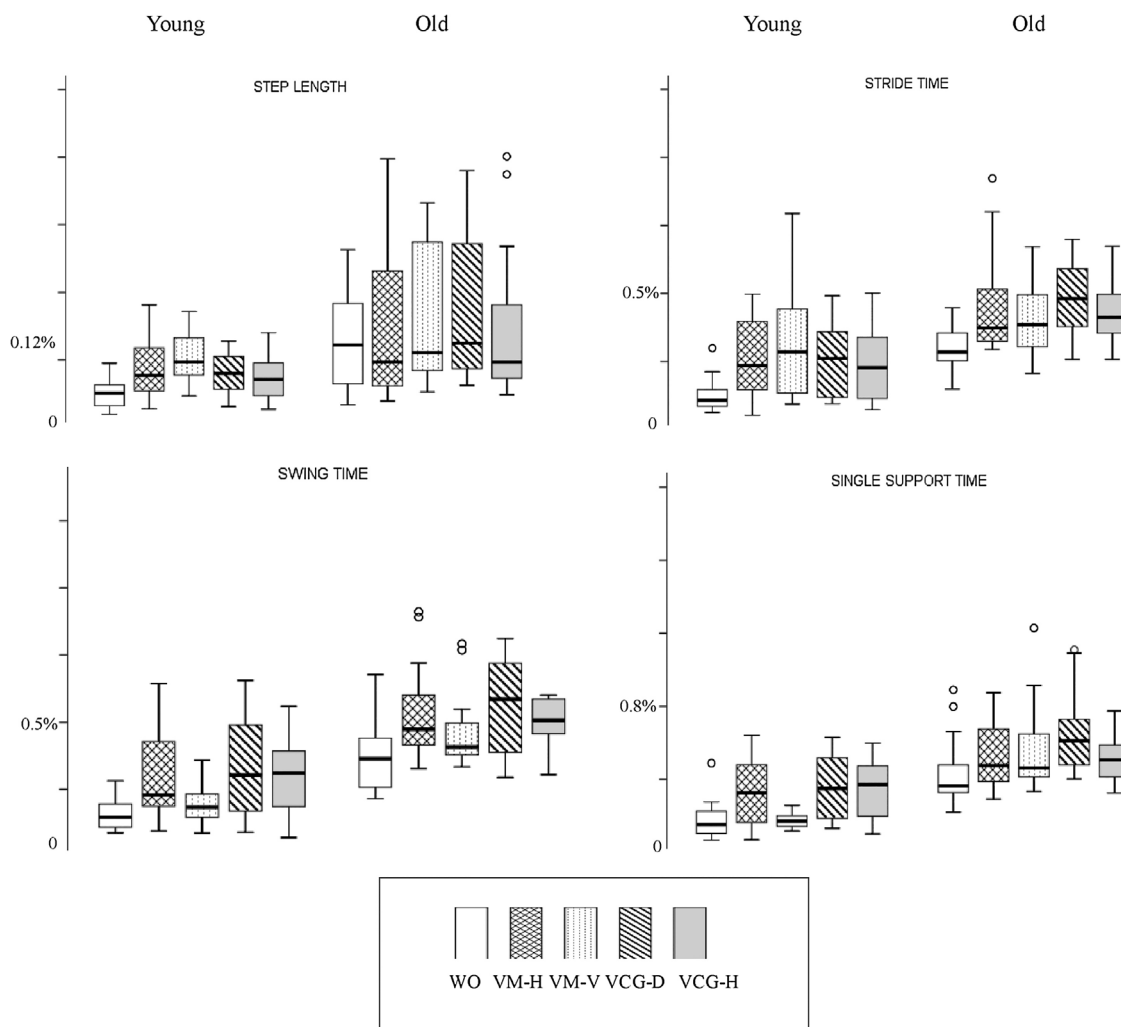
Fig. 5. Present box-plots, each box-plot represents the group medians and inter-quartile ranges (IQR) for different task conditions for the Coefficient of variation of the following gait variables; a) Step Length b) Stride Time c) Swing time, and d) Single support time in young and old age groups.

times greater. The VM task in the present study required continuous visual observation and head rotation. It also required utilization of visual feedback to maintain or restore the overlap between the moving objects. The task would represent a closed-loop process with respect to head motion as opposed to an open loop process whereby, the head is rotated in synchrony with a moving target similar to cyclic movements paced by a metronome. Jagacinski, Liao, and Fayyad (1995) had examined effects of aging on smooth pursuit using a tracking test similar to the present visuomotor tasks. The tracking task was done in sitting with no head movements, and the participants used a hand held joystick to move a computer cursor and follow a moving target presented on a computer monitor. Tracking error was computed as the difference between the position of the computer target and participants controlled cursor. This study reported that the old age group had a significantly higher tracking error than the young age group. This is consistent with the results of the present study, which additionally included active, as well as passive head motion and while walking. A large difference in VM performance between the old and young age groups may indicate that the old age group adopted an open-loop tracking strategy that required little attentional or computational load; one that used the turning points to guide and pace the cursor motion. An effective closed-loop strategy requires continuous visual attention to keep track of the position of two moving objects, and processing of visuospatial feedback (position error). Dual task walking had no effect on TRE in the old age group, whereas, the young age group showed a significant increase in

TRE while walking as compared to standing. To note, during treadmill walking there is a considerable amount of passive head motion (Szturm et al., 2013; Scherer, Migliaccio, & Schubert, 2008). Thus, during treadmill walking both the smooth pursuit system and the Vestibular ocular reflex (VOR) would be required to enable continuous fixation of the moving visual objects (circle and square). For a closed loop tracking task the increased passive head motion would explain the increased TSE while walking (Scherer et al., 2008). Interestingly, there was a substantial increase in gait variability (COV's) during the VM dual-task condition for the young age group, however, the old age group showed no change in gait performance with the addition of the VM task. These findings may be explained by the fact that different tracking strategies were used by the two groups, an open-loop strategy by the old age group with minimal cognitive load and the closed-loop strategy by the young age group with an increased cognitive load (continuous visual fixation and feedback processing).

In the present study, 28% of the participants from the old age group were unable to perform the VM dual tasks at 0.7 m/s. Assessors reported that these participants held onto the treadmill safety-rails during the tests. Although it was noted, these participants were able to walk hands-free and perform the VM task at a slower treadmill speed of 0.3-0.5 m/s. However, their data was excluded from the final analysis. This is an area that will receive further investigation, as to the factor(s) that could differentiate between the individuals who can and cannot perform the VM dual-task treadmill walking and how these relate to fall
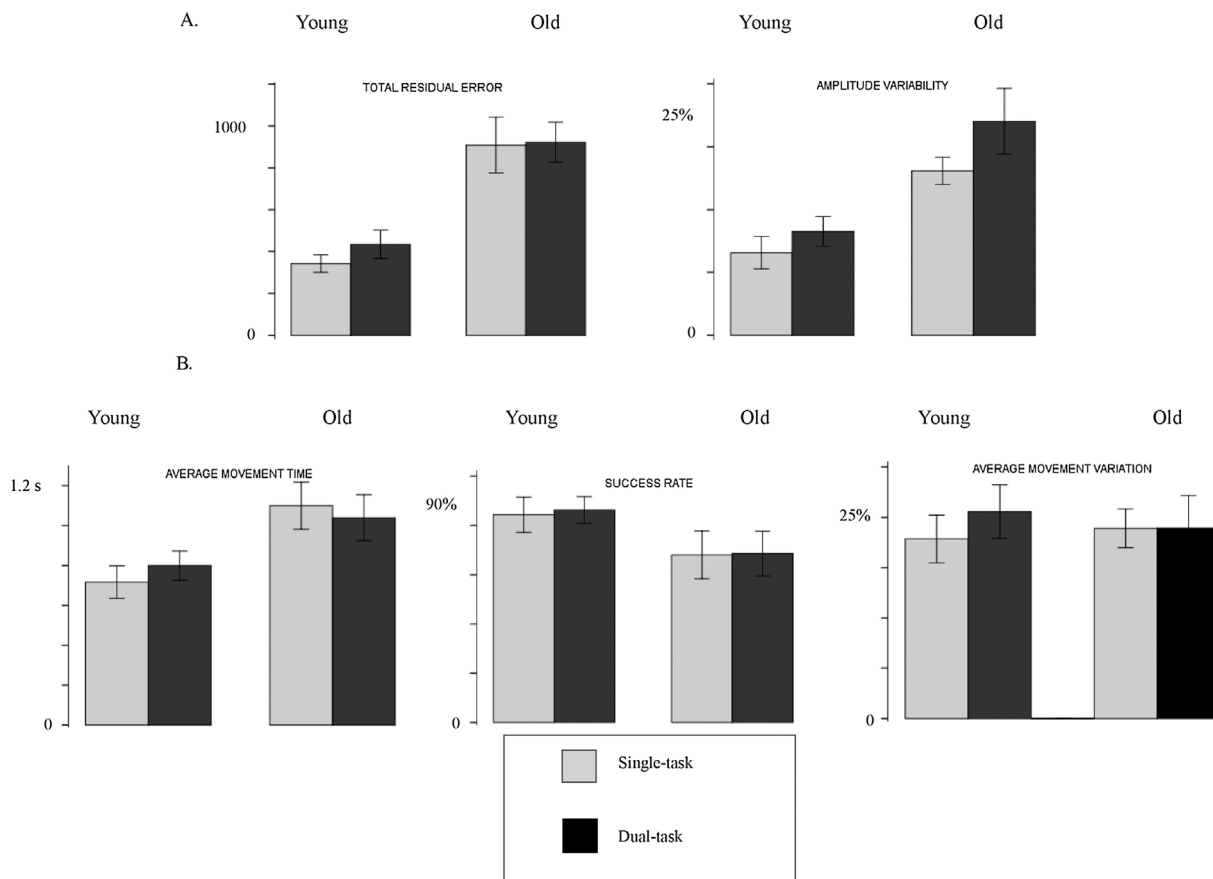
Fig. 6. Panel A Present bar-graphs, which represents the group means and standard error of mean (SEM) for a) Total Residual Error and b) Amplitude Variability.Panel B Present bar-graphs, which represents the group means and standard error of mean (SEM) for; a) Average Movement Time, b) Success Rate, and c) Movement Variation.

Table 2
Summarizes results of the Friedman comparison between walk alone (WO) and visuo-motor task (VM-H & VM-V) and walk alone (WO) and visuospatial cognitive tasks (VCG-D & VCG-V) for Average and COV gait variables in the young and old group.

GAIT VARIABLES	Visuomotor Tasks		Custom game	
	Young χ2, p-value, W	Old χ2, p-value, W	Young χ2, p-value, W	Old χ2, p-value, W
Avg-SL (cm)	6.077, 0.04, 0.9	0.12, 0.9	2.8, 0.2	7.4, 0.02, 0.95
Avg-ST (s)	1, 0.6	6.1, 0.04,0.9	**7, 0.02, 0.95**	**10, 0.006, 0.98**
Avg-SwT (s)	1.6, 0.4	2.3, 0.3	1.1, 0.5	7, 0.03, 0.9
Avg-SsT (s)	1.2, 0.5	1.1, 0.5	3,0.2	5.1, 0.056, 0.9
COV-SL	**5.6, 0.05, 0.9**	1.5, 0.4	2.7,0.3	1.4, 0.5
COV-ST	**6.2,0.04, 0.9**	4.6, 0.09	1.4, 0.5	**11.4, 0.003, 1**
COV-SwT	5.3,0.066,0.8	2.4,0.4	1.6, 0.4	**5, 0.05, 0.85**
COV-SsT	1.6,0.4	2.4,0.4	4,0.08, 0.2	**10, 0.005, 1**

df = 2, χ2 Chi Square statistics, COV's are expressed in percentages (%).
W effect size with 0.1 is weak, 0.3 is moderate and 0.5 and above is strong only presented for significant findings or for the ones who are approaching significance (0.05 > p < 0.1). SL step length, ST stride time, SwT Swing time, SsT Single support time.

risk.

The visuospatial cognitive game tasks employed in the present study were cognitively demanding, required timely responses (less than 1 s) to identify a moving object as a target or a distractor, to estimate the target object final position (straight and diagonal trajectories), and to move the game sprite using head rotation in order to interact with the

Table 3
Summarizes the results of a Two-way ANOVA for the effect of Physical demands (Load) and Age on visuomotor and visuospatial cognitive game tasks outcome measures.

Outcome Measures Visuomotor Task (VM-H)	Within group Load $F_{(1,16)}$, p-value, η2	Between group Age $F_{(1,16)}$, p-value, η2	Interaction term Load*Age $F_{(1,16)}$, p-value, η2
Total residual error	**111.7, 0.01, 0.8**	0.5, 0.4	0.1, 0.7
Amplitude Variation (%)	**84, 0.01, 0.8**	**4.2, 0.05, 0.2**	10, 0.01, 0.32
Visuospatial cognitive game task (VCG)			
Success Rate (%)	**14, 0.01, 0.4**	0.3,0.6	0.2, 0.7
Average Movement time (ms)	**42.5, 0.01, 0.7**	0.01, 0.9	1.3, 0.3
Movement Variation (%)	0.03, 0.8	2, 0.18	1.13, 0.3,

F- statistics, df degree of freedom, η2 is effect size 0.01 weak, 0.06 moderate and, 0.14 strong.

moving target, (i.e. accuracy requirement). Between-group comparison at baseline revealed that the old age group had a significantly lower success rate and much slower response times (almost two times greater than the young age group. A number of studies have shown that specific executive functions decline with age (Hoogendam, Hofman, van der Geest Jos, van der Lugt, & Ikram, 2014; Tombaugh, 2004). For example, there is a considerable decline in TMT-A & B, Digit and Symbol cancellation test and visual Stroop test scores as demonstrated by cross-sectional and longitudinal studies. These tasks require visuospatial attention, task-switching processing speed, and cognitive inhibition. Our findings using the VCG tasks are consistent with these results.

Similar to the present findings, Qu (2014) and Wollesen, Voelcker-Rehage, Regenbrecht, and Mattes (2016) reported a significant decrease in average step length or step time during dual-task treadmill walking in an old age group, but these tasks (i.e. stroop task (Qu, 2014) and Brook's spatial memory task (Wollesen et al., 2016) had no impact on the gait performance in a young age group during dual-task treadmill walking. Both studies also reported a significant decrease in the number of correct responses when performing the dual-task trials, but this was only seen in the old age group. The present study, which involved visuospatial tasks with visual targets and head motion also observed a substantial decline in Success Rate during the walking trials only in the old age group. However the opposite occurred for Response Time, a significant increase during walk trials only in the young age group. To note Response times for the old age group when tested in standing were much longer than that seen in the young age group, almost double. This may represent the upper limit for such a task and why Response Time did not increase during walk trials in the old age group. Response time, which in general is a proxy of information processing speed and other stages of motor planning, is typically measured over multiple events. The present study reports response time as well as response accuracy (Success Rate) over identical number of events for both age groups, which is not the case in previous studies

We assessed both young and old age groups for Visuomotor and visuospatial cognitive tasks at two levels of difficulty during dual-task walking. The horizontal and vertical visuomotor tasks had a similar impact on gait performance in both age groups. However, the visuospatial cognitive task involving a diagonal target trajectory had an effect on all gait performance measures, (i.e., both average and COV) whereas; the task which included a predictable straight path had an impact only on the average temporal gait variables. This demonstrates that different types of visuospatial processing do affect gait function in a different manner.

Different theoretical models have been proposed to explain dual-task interference (motor and cognitive). These include the following: a. Limited Resource Hypothesis: whereby the resources required for performing each task are independent of each other, but coordination (supervisory control) is required, and this can lead to decline in performance of one or both tasks. b. Cross-Domain Competition Model: whereby the resources needed to complete each task requires shared information and processing from the same region of the brain, and this would lead to a decline in performance of both tasks. c. Task Prioritization Model: suggests that during dual-tasking participants will prioritize the gait task (safety) over the cognitive task when balance may be threatened (Qu, 2014).

The Cross-domain competition model, best explains the findings of the present study. The young age group showed a decline in both gait and cognitive performance during the VM dual-task. This may point to the fact that this dual-task requires similar information processing resources, i.e., keeping track of spatial relationship between two moving objects and ones' spatial orientation relative to space while walking on a moving platform. Similarly, the old age group showed a substantial decline in both gait and visuospatial cognitive performance during the VCG dual-tasks walking trials. The young age group did not show any gait interference during the VCG dual task trials. One likely explanation for this is that active young adults have a greater information processing capacity than the old age group and their threshold for interference was not reached. The addition of the VM tasks to treadmill walking did not cause a decline in gait performance in the old age group.

4.1. Limitations

Treadmill walking does constrain gait, for example, by the belt width, and does not reflect all aspects of over ground walking behavior (Hollman et al., 2016). The DT tests were conducted at 0.7m/s, which may seem to be slow (England & Granata, 2007), but judging by the number of older adults who could not complete the test this is likely an

acceptable walking speed to use when testing dual-task effects and aging.

5. Conclusion

The computerized dual-task protocol presented in this study broadens the type of standardized visuospatial cognitive activities for use with treadmill walking that has previously been reported. A comprehensive analysis of spatial and temporal features of steady state gait has a greater validity to measure gait performance (rhythm, pacing, and stability) as compared to a single measure of stride time. Objective evaluation of the visuospatial cognitive tasks provide important information about different aspects of information processing, and helps to determine the level of engagement in dual-task situations. The use of interactive computer applications provides a flexible method to produce and evaluate a wide range of executive cognitive activities while performing complex motor behaviors such as; walking. Quantification of cognitive-motor interactions has the potential to be a valid non-invasive biomarker for early detection of balance-mobility limitations and cognitive impairments with aging.

Conflict of interest

None.

Financial interest

No author has expressed any financial interest.

Contributions

Dr.Tony Szturm and Mayur Nankar were involved in the concept, design, data collection, analysis and preparation of the manuscript.

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