Visuomotor control dynamics of quiet standing under single and dual task conditions in younger and older adults.

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Abstract

Visual input facilitates stable postural control; however, ageing alters visual gaze strategies and visual input processing times. Understanding the complex interaction between visual gaze behaviour and the effects of age may inform future interventions to improve postural control in older adults. The purpose of this study was to determine effects of age and dual task on gaze and postural sway dynamics, and the sway-gaze complexity coupling to explore the coupling between sensory input and motor output. Ten older and 10 younger adults performed single and dual task quiet standing while gaze behaviour and centre of mass motion were recorded. The complexity and stability of postural sway, saccade characteristics, visual input duration and complexity of gaze were calculated in addition to sway-gaze coupling quantified by cross-sample entropy. Dual tasking increased complexity and decreased stability of sway with increased gaze complexity and visual input duration, suggesting greater automaticity of sway with greater exploration of the visual field but with longer visual inputs to maintain postural stability in dual task conditions. In addition, older adults had lower complexity and stability of sway than younger adults indicating less automated and stable postural control. Older adults also demonstrated lower gaze complexity, longer visual input durations and greater sway-gaze coupling. These findings suggest older adults adopted a strategy to increase the capacity for visual information input, whilst exploring less of the visual field than younger adults.

Keywords: Eye tracking, dual task, postural control, complexity, aging, cross-sample entropy

Introduction

Postural control requires the complex integration of sensory information to maintain stability. Previous research has demonstrated that cognitive motor interference, elicited by cognitive dual tasking, increases the complexity of postural sway in younger and older adults, which has been suggested to be indicative of increased automaticity of postural sway, or a reduced contribution of cognitive resources to postural control [1–3]. Older adults also demonstrate lower postural control complexity than younger adults [4,5], less complex postural control is interpreted as more constrained and less robust [6].

Older adults demonstrate less functional connectivity between the prefrontal cortex and the sensorimotor cortex than younger adults which may account in part for the age related decline in postural stability [7]. Given the role of the prefrontal cortex in cognitive control and its role in demanding standing balance tasks [8–10] a loss in functional connectivity between these areas could explain the greater impact of cognitive motor interference on the postural control of older adults [7], and the decline in sensorimotor function with age [11–13]. Greater movement reinvestment, or internal focus of attention on movement production and control, may also increase the cognitive resources required for postural control in older adults [14–16], having a compounding effect on postural control during cognitive motor interference. It has also been shown that older adults have a greater reliance on the visual frame of reference for executing sensorimotor tasks [12] and that older adults with poorer sensorimotor function show greater power in lower frequency components of postural sway [13] which has been associated with a greater contribution of visual sensory input to postural control [17].

Previous evidence suggests that visuomotor function is altered by age with older adults demonstrating different visual search strategies during obstacle crossing [18], longer fixations when approaching stairs [19] and restricted eye movement range of motion [20]. Additionally, fallers demonstrate earlier gaze shifts when obstacle crossing than non-fallers [21] and ageing reduces visual tracking ability in quiet and perturbed quiet standing [22]. Together these findings suggest that older adults, and those at greatest risk of falling, require longer durations to process the visual sensory information to control movement. This may be due to a decline in executive function [23], loss of visual acuity [24], fear of falling [25] and re-allocation of cognitive resources to conscious movement control [26].

Measurements of gaze fixations and saccades are commonly used to quantitatively assess gaze behaviour [23]. Fixations are defined as periods where the gaze rests on an area and is the period in which visual sensory input is attained, whereas, saccades are the rapid movements between fixations during which visual input is suppressed [23,27]. On the other hand the complexity of the gaze path has been used to investigate neural visuomotor control strategies [28–30], and the coupling of gaze and sway complexity to understand postural control mechanisms in tracking tasks [31,32], however this relationship has not been examined during quiet standing. An increase in gaze complexity represents greater visual exploration to increase the amount of information gained about the visual field [28,29]. The effects of ageing on gaze complexity during quiet standing balance tasks have not been investigated. Previous literature has suggested that suppression of eye movements reduces postural sway [33] and longer, static fixations provide a more stable visual reference and retinal flow [34], and less noisy extraocular muscle proprioceptive feedback responsible for postural shifts [35]. These findings indicate a more constrained, less complex gaze behaviour is associated with reduced postural sway. However, previous research has indicated that more complex, autonomous sway is associated with more robust postural control in younger adults [4–6]. When the findings of reduced sway with constrained gaze behaviour are considered, it could be expected that if younger adults have more complex, less constrained sway they will have concurrent greater gaze complexity. By investigating the concurrent changes in gaze and postural sway complexity and the coupling of gaze behaviour and postural sway in response to cognitive motor interference we can gain novel insight into the effects of age on visuomotor control of standing posture. These findings could additionally inform future balance and falls risk reduction interventions that are focussed on the role of gaze behaviour in challenging balance tasks.

The aim of this study was to determine the effects of ageing and cognitive motor interference on gaze and postural control complexity and the gaze-sway complexity coupling. It was hypothesised that changes in postural sway complexity and visual gaze complexity would correspond and that both would be greater in dual task compared to single task conditions. Additionally, it was hypothesised that gaze and postural sway complexity would be lower in older adults and that the effects of dual task would be greater in older adults than young. It was also hypothesised that postural sway dynamic stability would be greater in younger adults and would be lower in dual task conditions with dual task effects greater in older adults than younger. Finally, it was hypothesised that gaze-sway coupling would be lower in older than younger adults and that dual tasking would decrease coupling.

Methods

Participants

Twenty participants volunteered for the study, including 10 older adults and 10 younger adults (Table 1). The height, body mass and BMI were similar between age groups. All participants were free from neurological, vestibular and orthopaedic conditions and had normal or corrected to normal vision. Participants were explained the purpose of the study, all procedures and their right to withdraw at any time, before providing written informed consent. The study was granted ethical approval by the Oxford Brookes University Research Ethics Committee and all study protocols were conducted in accordance with the Declaration of Helsinki.

Procedures

Participants attended a single laboratory session during which gaze behaviour and postural sway of the centre of mass (COM) were recorded during quiet standing under single task (ST) and dual task (DT) conditions. Participants performed 3 60 second trials of barefoot quiet standing each in a control condition (CON) and a cognitive DT condition. The order participants completed each of the 6 trials was randomised. In all conditions participants stood facing a TV monitor positioned with the centre of the monitor at approximately eye level and at a distance of 2 m. The TV monitor was positioned on a white wall and medical privacy screens were positioned on either side of the participant at a distance of 2 m each side to reduce the likelihood of visual distractions in the peripheral vision of participants. Participants were asked to adopt a comfortable stance position and the foot position was marked on the floor to ensure consistent foot placing between trials.

In CON, participants were asked to stand comfortably but were given no additional instructions as to their gaze behaviour and the TV monitor displayed a white screen. For DT trials participants were required to count aloud backwards by 7's from a randomly generated 3-digit number. The 3-digit number was displayed on the TV monitor for 2 seconds after which the screen returned to white and the 60 second trial commenced.

During each trial a 9-axis inertial measurement unit (IMU: LPMS-B2, Life Performance Research, Tokyo, Japan) was attached over the L5 vertebrae to measure the movements of the COM, recording at 100 Hz. Participants also wore a pair of mobile eye tracking glasses (Natural Gaze Eye Tracking Glasses, SensoMotoric Instruments, Teltow, Germany) which recorded binocular pupil position to an accuracy of 0.5° and precision of 0.3° at 60 Hz using infrared cameras aimed at each eye.

Postural control analysis

For each quiet standing trial in each condition the first and last 2 seconds of data were excluded and the middle 5600 data points were analysed. The acceleration signals were not filtered to ensure all relevant information was retained [36,37]. All postural control analysis was completed using custom MATLAB programmes (2016b, The MathWorks, Inc., Natick, USA).

Multiscale entropy (MSE) was used to determine the complexity of the anterior-posterior (AP), medio-lateral (ML) and vertical (VT) acceleration signals, separately. Consecutively more course-grained time series were calculated from the original acceleration signals by averaging data points in non-overlapping windows of length τ; τ ranged from 1-20 data points. A τ of 20 represents a scale of 200 ms for the IMU signals which is representative of visuomotor delays [38]. From each course-grained time series the sample entropy (SE) was calculated as the negative natural logarithm of the conditional probability, C(*r*), that two sequences of *m* consecutive data points within a radius of $r\delta$ of each other will remain close when one more point is included, where δ is the standard deviation of the original signal, and the values of *m* and *r* were set at 2 and 0.2, respectively:

$$SE = -ln\frac{C^{m+1}(r)}{C^{m}(r)}$$

After calculation of the sample entropy at each course-grained time scale, the complexity index (CI_{COM}) was calculated as the area under the curve of SE vs. τ to provide an indication of overall complexity:

$$CI = \sum_{i=1}^{20} SE(i)$$

A higher CI value represents greater complexity.

The local dynamic stability of the acceleration signals was determined separately for each direction as the maximum Lyapunov exponent (MLE_{COM}) using the Rosenstein algorithm [39]. A state space was reconstructed for each acceleration signal using the method of time delays:

$$X(t) = [x(t),x(t+T),x(t+2T),\ldots,x(t+(d_E-1)T]$$

Where $X(t)$ is the state space vector, $x(t)$ is the acceleration time series, T is the time delay and d_E is the embedding dimension. Time delays were calculated separately for each direction from the first of the minimum of the average mutual information function, the average delays used were 27, 32 and 30 for the ML, VT and AP directions respectively. The d_E was determined by global false nearest neighbours analysis and a value of was determined to be appropriate for each direction. For each point in the reconstructed state space all nearest neighbours were identified with a temporal separation equivalent to the mean period of the signal. The Euclidean distance between pairs of nearest neighbours, $d_j(i)$, was then calculated for each point on the two trajectories. For each pair of points the $d_j(i)$ was averaged to produce the average divergence as a function of time. The MLE_{COM} was then determined as the slope of the $\langle \ln d_j(i) \rangle$ vs. time plot over the period of 0-0.75 s [40].

Gaze behaviour analysis

Analysis of gaze data was completed in BeGaze software (SensoMotoric Instruments, Teltow, Germany) and using custom MATLAB programmes (2016b, The MathWorks, Inc., Natick, USA). The first and last 2 seconds of data were discarded before analysis. For each trial, from the binocular gaze vector time series, determined as the resultant of the horizontal and vertical gaze positions, fixations and saccades were identified. Saccades were defined as periods of eye rotation that exceeded 100°/s and fixations were defined as periods of at least 50 ms bordered immediately before and after by a saccade [22]. In contrast, the COM motion was analysed for the separate directions due to the different mechanical constraints in each direction which require varying postural control strategies.

The frequency of saccades ($SACC_{FREQ}$) was determined as the number of saccades per second and the duration of saccades ($SACC_{DUR}$) as the average duration of all saccades in a trial. The visual input duration (VIS_{IN}) was determined as the average duration of all fixations in a trial. Finally, from the resultant gaze vector time series with blinks removed the complexity of gaze behaviour was determined using MSE as described in the previous section. The gaze vector was used to calculate the complexity of gaze behaviour as it will contain the range of eye movements including saccades, micro-saccades, fixations, post-saccadic oscillations and vestibulo-ocular reflex movements. Therefore, the MSE of the gaze vector was considered to represent the overall dynamics of gaze behaviour, in addition to the discretised saccade measures. Blinks were automatically detected and flagged by BeGaze software. For the gaze vector time series τ ranged from 1-12 data points, a τ of 12 represents a scale of ~200 ms for the gaze signal which is representative of visuomotor delays [38]. The gaze CI (CI_{GAZE}) was calculated as described in the previous section. The resultant gaze vector was utilised as opposed to the individual components separately as no constraints were provided to gaze position in either condition and therefore gaze shifts were free to move in either direction or a combination (resultant) of both. It was therefore decided that the resultant gaze vector would sufficiently capture the gaze dynamics.

Gaze and COM cross-sample entropy

To determine the coupling between gaze behaviour and COM motion complexity the cross sample Entropy (XSampEn) was calculated between the resultant gaze vector and the acceleration data separately for each axis. The first and last 2 seconds gaze and acceleration data were discarded and gaze data were interpolated to have equal length to the acceleration data, 5600 samples, as the calculation of XSampEn requires each time series to have the same length. The process for calculating XSampEn has been described in detail previously [41,42]. Briefly, before calculating the XSampEn the data were normalised to have 0 mean and standard deviation of 1. For the input parameters *m* and *r* and the normalised gaze vector time series x(i) and normalised acceleration time series y(i)(1≤i≤N), where N is the number of samples, the vectors X_i^m and Y_j^m, representing *m* consecutive *x* and *y* values respectively, were created:

$$X_i^m = \{x(i), x(i+1), \ldots, x(i+m-1)\}$$

$$Y_j^m = \{y(j), y(j+1), \ldots, y(j+m-1)\}$$

$$1 \leq i, j \leq N - m$$

The distance between X_i^m and Y_j^m, determined as the maximum absolute difference, was calculated as:

$$d_{i,j}^m = d\left[X_i^m, Y_j^m\right] = \max_{k=0}^{m-1} |x(i+k) - y(j+k)|$$

For each X_i^m, $set\ B_i^m(r)$ is denoted as $(N\text{-}m)^{-1}$ multiplied by the number of Y_j^m $(1 \leq j \leq N - m)$ that meet the criteria $d_{i,j}^m \leq r$ and set $A_i^m(r)$ is denoted as $(N\text{-}m)^{-1}$ multiplied by the number of $Y_j^{m+1}(1 \leq j \leq N - m)$ that meet the criteria $d_{i,j}^{m+1} \leq r$. The XSampEn is then determined as:

$$XSampEn(m,r,N) = -\ln\left(\frac{\sum_{i=1}^{N-m} A_i^m(r)}{\sum_{i=1}^{N-m} B_i^m(r)}\right)$$

Values of m=3 and r=0.25 were used based on previous recommendations for determining the XSampEn between biological signals [42]. For each trial condition XSampEn was calculated between the gaze vector and each of the acceleration axes separately and then averaged to provide a single XSampEn value per trial. Higher values of XSampEn represent less closely coupled signals. Therefore, a lower XSampEn in this study demonstrated a greater degree of coupling between the complexity of gaze behaviour and COM motion.

Statistics

Data were tested for normality using the Shapiro-Wilk test. Participant height, mass and BMI were compared between age groups (Table 1). An omnibus 2x2 mixed design MANOVA was used to determine the effects of age group and conditions on postural control and gaze behaviour and age group x condition interactions using the Wilk's Lambda (λ) test statistic. For significant multivariate main and interaction effects univariate two-way mixed design ANOVA were performed. For the MANOVA and subsequent ANOVA partial eta squared (η_p^2) effect size was calculated, values of 0.01, 0.06 and 0.14 represent small, moderate and large effects, respectively [43,44]. For all tests the level of significance was $p < 0.05$. All statistical analysis was performed using SPSS (v26, IBM Corp., NY, USA).

Results

There was a multivariate effects of age (λ = 0.13, F(11,8) = 4.69, p = 0.019, η_p^2 = 0.87) and condition (λ = 0.13, F(11,8) = 4.79, p = 0.017, η_p^2 = 0.89) on postural control and gaze behaviour, however there was no multivariate interaction effect (λ = 0.39, F(11,8) = 1.15, p = 0.434, η_p^2 = 0.61).

All postural control dynamics data are given in Figure 1. DT was greater than ST for AP CI_{COM} (F(1,18) = 5.20, p = 0.035, η_p^2 = 0.22), ML MLE_{COM} and VT MLE_{COM} (ML MLE_{COM}: F(1,18) = 9.00, p = 0.008, η_p^2 = 0.33, VT MLE_{COM}: F(1,18) = 14.83, p = 0.001, η_p^2 = 0.45). However there was no effect of condition on ML CI_{COM} or VT CI_{COM} (ML CI_{COM}: F(1,18) = 1.71, p = 0.208, η_p^2 = 0.09, VT CI_{COM}: F(1,18) = 0.12, p = 0.733, η_p^2 = 0.01) and AP MLE_{COM} (F(1,18) = 4.19, p = 0.055, η_p^2 = 0.19). Significant age group effects were present for ML CI_{COM} with younger adults greater than older adults (F(1,18) = 7.60, p = 0.013, η_p^2 = 0.30) and AP MLE_{COM} and ML MLE_{COM} was greater in older adults than younger adults (AP MLE_{COM}: F(1,18) = 4.56, p = 0.047, η_p^2 = 0.20, ML MLE_{COM}: F(1,18) = 4.41, p = 0.048, η_p^2 = 0.20). However, there was no effect of age group for VT CI_{COM} and AP CI_{COM} (VT CI_{COM}: F(1,18) = 0.30, p = 0.589, η_p^2 = 0.02, AP CI_{COM}: F(1,18) = 1.86, p = 0.189, η_p^2 = 0.09) or VT MLE_{COM} (F(1,18) = 0.35, p = 0.560, η_p^2 = 0.02).

[Insert Figure 1 here]

Example gaze trajectories are shown in Figure 2 and all visual gaze behaviour dynamics are given in Figure 3. There was a significant effect of condition on CI_{GAZE} (F(1,18) = 54.40, p < 0.001, η_p^2 = 0.75) and VIS_{IN} (F(1,18) = 5.18, p = 0.035, η_p^2 = 0.22), CI_{GAZE} and VIS_{IN} were greater in DT than ST. However there was no effect of condition on $SACC_{FREQ}$ (F(1,18) = 0.74, p =

0.401, η_p^2 = 0.04) or $SACC_{DUR}$ (F(1,18) = 0.63, p = 0.439, η_p^2 = 0.03). The CI_{GAZE} was greater in younger than older adults (F(1,18) = 17.30, p = 0.001, η_p^2 = 0.49) and VIS_{IN} was greater in older than younger adults(F(1,18) = 11.98, p = 0.003, η_p^2 = 0.40), however there was no effect of age on $SACC_{FREQ}$ (F(1,18) = 0.41, p = 0.528, η_p^2 = 0.02) or $SACC_{DUR}$ (F(1,18) = 0.50, p = 0.488, η_p^2 = 0.03).

[Insert Figure 2 here]

[Insert Figure 3 here]

The XSampEn values are given in Figure 3. XSampEn was greater in younger than older (F(1,18) = 5.24, p = 0.034, η_p^2 = 0.23). However, there was no significant effect of condition on XSampEn (F(1,18) = 4.24, p = 0.054, η_p^2 = 0.19) or interaction effect (F(1,18) = 1.23, p = 0.281, η_p^2 = 0.06).

[Insert Figure 4 here]

Discussion

The purpose of this study was to determine the effects of age and cognitive motor interference, elicited by cognitive dual task conditions, on visual gaze dynamics and postural control during quiet standing. It was found that older adults had less complex postural sway and gaze behaviour with longer visual input durations. However, older adults had greater coupling between gaze and sway complexity than younger adults. These findings may provide novel insight into the effects of age on postural control mechanisms. Performing cognitive dual tasks increased sway stability and complexity. Gaze complexity and stability were also increased during dual task conditions.

The greater ML postural sway complexity in younger adults compared to older adults demonstrated in this study is in agreement with previous studies that have demonstrated lower complexity of postural sway in older adults compared to young [4,5]. Less complex postural sway can be interpreted as more constrained, less adaptive postural control [6,45]. The lower complexity likely contributed to the lower postural stability found in older than younger adults in this study, as demonstrated by the greater MLE_{COM} in the ML direction [5,46].

As in previous studies, AP sway complexity increased in dual task conditions, indicative of increased postural control automaticity with increased cognitive demand [1–3]. However, the results of this study indicated no change in ML or VT sway complexity . Interestingly, sway stability was greater in dual task conditions for the ML and VT directions. It is possible that the increased automaticity in the AP direction attenuates the reduction in dynamic stability.

Concurrently, dual task conditions increased both the complexity of gaze behaviour and visual input durations. This finding may be explained by the role of the prefrontal cortex in both dual tasking [8,47–50] and in modulating activity in the visual cortex [51,52]. Increased prefrontal cortex activity resulting from dual tasking may therefore have reduced available resources for visual processing, causing alterations in gaze behaviour, leading to longer visual input durations and more complex gaze behaviour.

The present study also provides evidence for significant effects of age on visual gaze behaviour. The greater VIS_{IN} duration in older than younger adults may be a compensation for the greater time required to process visual information in older compared to younger adults [53]. However, it has also been demonstrated that longer duration fixations with suppressed eye movements reduce postural sway [33]. As ageing impairs the function of neuromuscular structures associated with balance and postural control [54–56], the longer VIS_{IN} and less complex gaze may represent a strategy that maximises stability of retinal flow and minimises extraocular muscle actions, which cause sway shifts [35], thus reducing neuromuscular demand for postural corrections. This would appear to represent an opposing postural control strategy to that adopted by younger adults, who demonstrated more complex sway and gaze. A possible interpretation of this difference is that the greater neuromuscular function of younger adults allows for more postural sway automaticity (i.e. greater complexity), thus allowing for greater gaze complexity, indicative of greater exploration of the visual field providing more foveal information from the surrounding environment. Alternatively, the more complex eye movements may be required to stabilise the retinal image on the fovea in response to the more complex postural movements in younger adults. However, the findings of this study do not allow for further clarification on this relationship which warrants further study.

While the findings of this study do not categorically provide a causal link between gaze complexity and postural sway complexity, and the effects of age on this coupling, a possible interpretation of the greater gaze-sway coupling in older adults than young is that the motor output (i.e. postural sway) complexity is a function of the complexity of sensory input (i.e. gaze) complexity. Since ageing results in lower automaticity of postural sway [1–3,57] it is likely a greater cortical contribution is required to maintain balance in older adults [1,54,57]. This is in turn reflected in the greater coupling between sensory input and motor output, in agreement with studies demonstrating high reliance on visual information for postural control in older adults [58].

The results of this study indicated no effect of age or DT on saccade behaviour. This may indicate that despite changes in complexity and VIS_{IN} the saccade behaviour is robust to the conditions examined in the present study. This finding may be due to the design of the present experiment. Previous studies demonstrating age and task effects on saccade behaviour have performed specific gaze tasks such as tracking a target [22,59]. Saccadic movements play a vital role in motion tracking as they serve to reposition the eye, therefore, tasks that require this function are more likely to discriminate age DT condition effects than the experimental design of the current study.

Contrary to the hypothesised effects for all variables the results of this study demonstrated no significant interaction effects indicating that both younger and older adults responded similarly to cognitive motor interference despite extant age group differences. It is possible that given the relative simplicity of the postural task of standing quietly on two feet used in this study, that the combination of DT and quiet standing was not sufficiently challenging to elicit the hypothesised interaction effects. In addition, the use of active, healthy older adults may not be representative of the effects on less stable older adult populations where greater neuromuscular impairment would be expected. There were further limitations of the current study that should also be considered. Firstly, whilst the relatively simple DT condition adopted resulted in effects on gaze and postural control, a more complex task or a task that required both cognitive and motor dual tasking may have elicited age and DT interactions that were not detected in the current study. Additionally, postural control was assessed during quiet standing only, a more dynamic postural task may have more relevance for activities of daily living, however, static, quiet standing is sensitive to changes in neuromotor control.

Conclusions

The present study provides a novel insight into the effects of cognitive dual tasks on visual gaze behaviour and the effects of age on visual postural control mechanisms. Dual task conditions increased sway complexity concurrently with increased gaze complexity and visual input durations. Older adults also demonstrated lower complexity and stability of sway than younger adults in conjunction with longer visual input durations and less complex gaze. These findings suggest alternate postural control strategies between older and younger adults. Older adults relied on longer visual inputs with less exploration of the visual field to minimise sway through extraocular control mechanisms, whilst younger adults did not constrain their gaze behaviour to the same extent, exploring more of the visual field with greater automaticity of postural sway.

Declaration of Interests

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Figure captions

Figure 1. Box plots for the medio-lateral (ML), vertical (VT) and anterior-posterior (AP) postural sway complexity index (CI_{COM}) and maximum Lyapunov exponent (MLE_{COM}) in younger and older adults under single (ST) and dual task (DT) conditions. The Individual data points are indicated by circles and the mean for each group in each condition is represented by an X. The upper, middle and bottom horizontal line of each box represent the 1st quartile, median and 3rd quartile of the data, respectively, and the error bars indicate the minimum and maximum values.

* indicates DT is greater than ST

** indicates younger adults are greater than older adults

† indicates older adults are greater than younger adults

Figure 2. Example gaze trajectories for younger adults in single task (A) and dual task (B) conditions and older adults in single task (C) and dual task (D) conditions. Data have been centred for ease of comparison.

Figure 3. Box plots for the gaze complexity index (CI_{GAZE}), average visual input duration (VIS_{IN}), saccade frequency ($SACC_{FREQ}$) and average saccade duration ($SACC_{DUR}$) in younger and older adults under single (ST) and dual task (DT) conditions. The Individual data points are indicated by circles and the mean for each group in each condition is represented by an X. The upper, middle and bottom horizontal line of each box represent the 1^{st} quartile, median and 3^{rd} quartile of the data, respectively, and the error bars indicate the minimum and maximum values.

* indicates DT is greater than ST

** indicates younger adults are greater than older adults

† indicates older adults are greater than younger adults

Figure 4. Box plots for the cross-sample entropy (XSampEn) between gaze and COM motion for younger and older adults under single (ST) and dual task (DT) conditions. The Individual data points are indicated by circles and the mean for each group in each condition is represented by an X. The upper, middle and bottom horizontal line of each box represent the 1^{st} quartile, median and 3^{rd} quartile of the data, respectively, and the error bars indicate the minimum and maximum values.

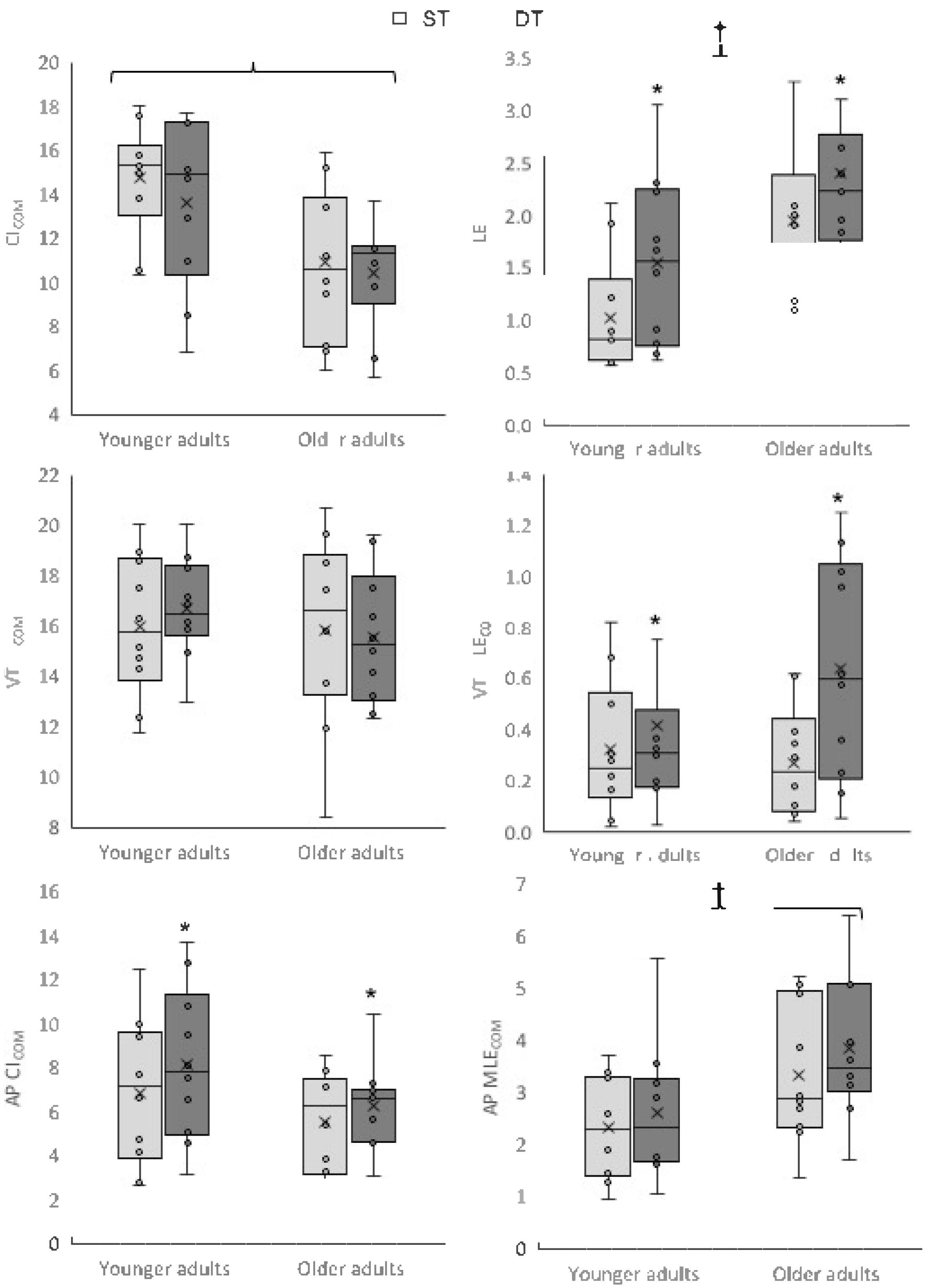
** indicates younger adults are greater than older adults

Table 1. Participant characteristics for the younger and older adult groups and group differences.

Group	Age (yrs)	Height (m)	Mass (kg)	BMI ($kg \cdot m^{-2}$)
Younger adults	22±2	1.78±0.11	77.7±14.3	24.4±2.4
Older adults	69±17	1.71±0.12	75.1±16.2	25.4±3.7
Group difference p-value		0.237	0.710	0.490

CRediT author statement

Gregory S Walsh: Conceptualisation, Methodology, Investigation, Data curation, Software, Formal analysis, Writing- Original draft preparation, Visualisation.



ST
DT
CI COM
Younger adults
Old r adults
LE
Young r adults
Older adults
VT COM
Younger adults
Older adults
VT LE
Young r . dults
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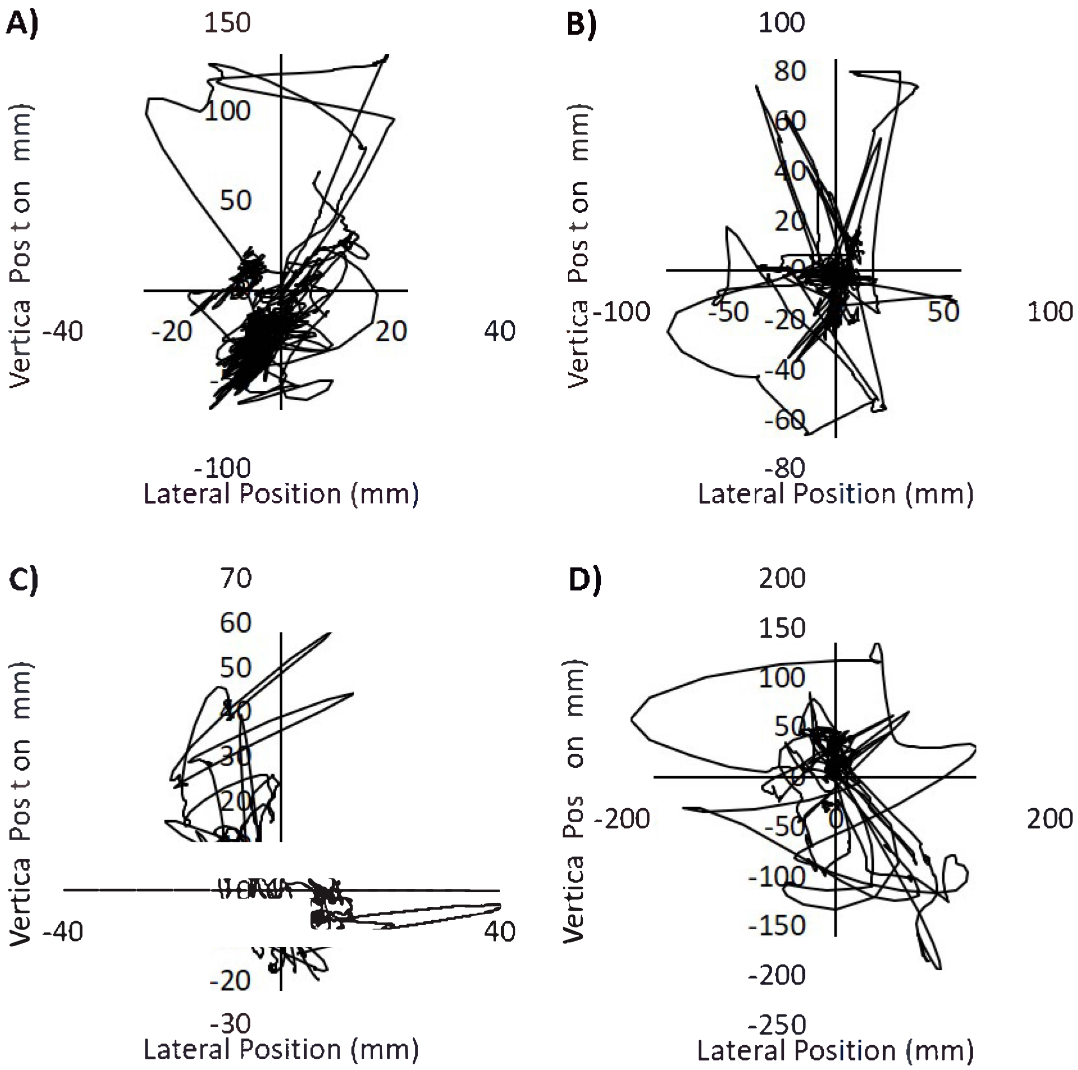
AP CI COM
Younger adults
Older adults
AP MLE COM
Younger adults
Older adults



A)
150
100
50
-40
-20
20
40
-100
Vertica Pos t on mm)
Lateral Position (mm)
B)
100
80
60
40
20
-100
-50
50
100
-20
-40
-60
-80
Vertica Pos t on mm)
Lateral Position (mm)
C)
70
60
50
40
30
20
-40
40
-20
-30
Vertica Pos t on mm)
Lateral Position (mm)
D)
200
150
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50
-200
-50
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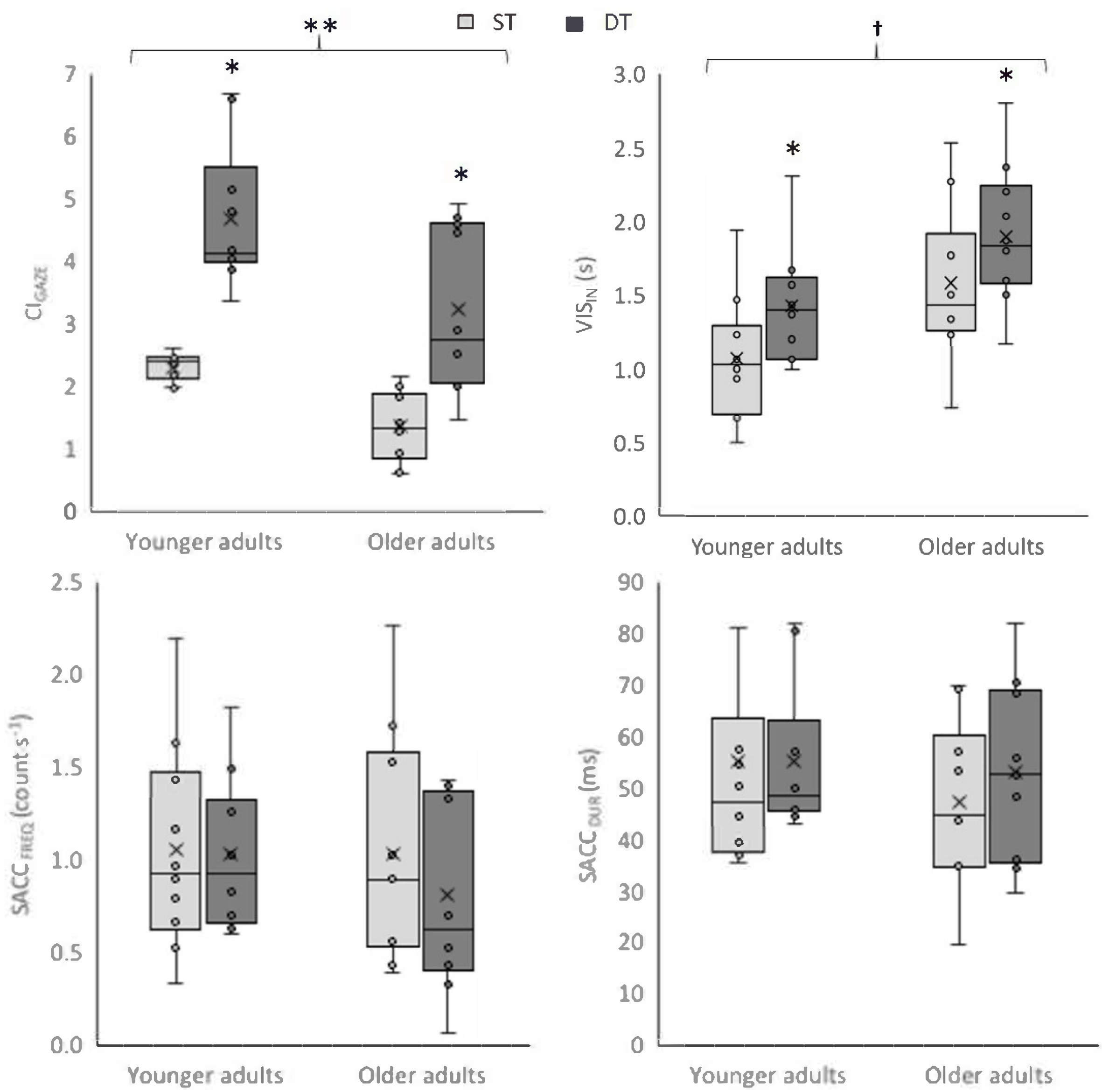
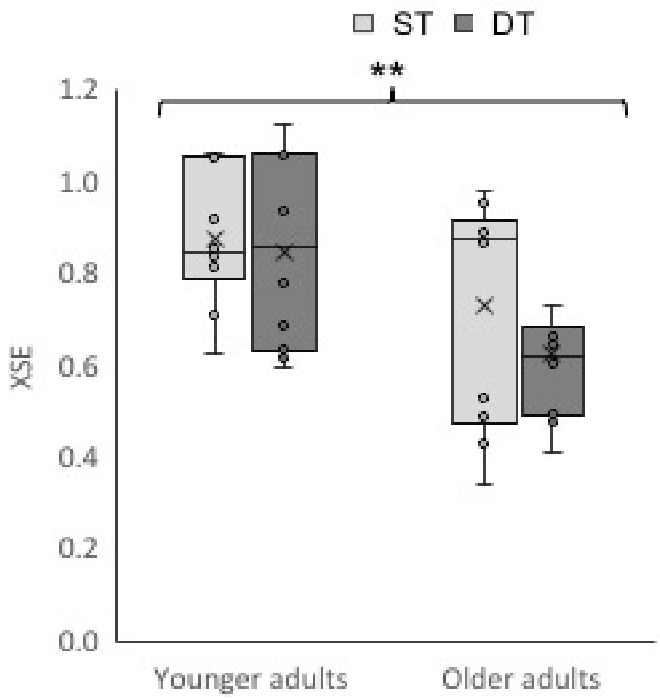
200
-100
-150
-200
-250
Vertica Pos on mm)
Lateral Position (mm)



ST
DT
**
*
*
†
*
*
CI_{GAZE}
VIS_{IN} (s)
$SACC_{FREQ}$ (count s^{-1})
$SACC_{DUR}$ (ms)
Younger adults
Older adults



Highlights

- Sway-gaze coupling was greater in older than younger adults
- Gaze complexity was lower and visual input greater in older than younger adults
- Gaze complexity was greater and visual input greater in dual task conditions
- Postural sway complexity was greater and stability was lower in dual task conditions
- Postural sway complexity and stability were lower in older than younger adults