Visually fixating or tracking another person decreases balance control in young and older females walking in a real-world scenario

Neil M. Thomas*[1,2], Tim Donovan[1], Susan Dewhurst[3], Theodoros M. Bampouras[1]

1. Department of Medical and Sport Sciences, Active Ageing Research Group, University of Cumbria, Lancaster, LA1 4DH, UK
2. Research Institute for Sports and Exercise Sciences, Liverpool John Moores University, Liverpool, L3 3AF, UK
3. Department of Sport and Physical Activity, Bournemouth University, Dorset, BH12 5BB, UK

*E-mail: N.M.Thomas@ljmu.ac.uk

Highlights

1. Balance control was decreased in young and older adults similarly when fixating or tracking another person
2. Older adults exhibited lower baseline stability than young adults during free gaze, and when fixating or tracking another person
3. Free gaze in an uncluttered environment generated the most optimal balance outcome in young and older adults

Abstract

Balance control during overground walking was assessed in 10 young (23.6 ± 3.4) and 10 older (71.0 ± 5.5 years) healthy females during free gaze, and when fixating or tracking another person in an everyday use waiting room. Balance control was characterised by medial/lateral sacrum acceleration dispersion, and gaze fixations were simultaneously assessed with eye tracking equipment. The results showed decreased balance control when fixating a stationary (p=0.003, g_{av}=0.19) and tracking a walking (p=0.027, g_{av}=0.16) person compared to free gaze. The older adults exhibited reduced baseline stability throughout, but the decrease caused by the visual tasks were not more profound than the younger adults. The decreased balance control when fixating on or tracking the observed person was likely due to more challenging conditions for interpreting retinal flow, which facilitated less reliable estimates of self-motion through vision. The older adults may also have adopted a more rigid posture to facilitate visual stability, which attenuated any ageing

effect of the visual tasks. The decrease in balance control, the first to be shown in this context, may warrant further investigation in those with ocular or vestibular dysfunction.

Keywords: elderly gait, eye movements, postural control, smooth pursuits, trunk accelerations, walking balance

1. Introduction

Vision helps maintain an upright posture during locomotion [1,2]. This is facilitated by changes in patterns of light intensities caused by relative motion between an observer and their environment, which are sensed at the retina. Lateral trunk lean, for example, would generate a translational flow on the retina in the opposite direction [3]. The central nervous system uses this to estimate shifts in body position and initiate postural adjustments [4]. Eye movements can change the structure of retinal flow, and this has previously been suggested to affect balance control during locomotion. That is, visually tracking a moving target with smooth pursuits led to increased medial/lateral (ML) trunk movement and step-width variability in young and older adults [5]. During such eye movements, although the target of fixation is stabilised on the fovea, the background information invariably shifts on the retina in the direction opposite to the eye rotation [6]. This seems to make it more difficult to estimate self-motion through visual means, which is similar to that shown in standing experiments [7–9].

During our previous investigation [5], the visual target was projected in 2D at one end of the laboratory. Humans often, however, fixate and track 3D objects located more in the foreground, such as another standing or walking person in the field of view [10]. This would change the structure of retinal flow when compared to a 2D target. Because the person would be closer to the observer relative to the background, there would be defocus blur to regions immediately surrounding the person [10]. Further, the relative distance would generate motion parallax, with the retinal image of the region behind the person shifting in the direction of the observer's movements [11]. Of interest is whether these factors would generate a different balance response in an observer when compared to our previous investigation.

Previous studies examining parallax and balance control during locomotion have typically used corridor style paradigms [12,13]. These do not create the same defocus blur or parallax which would occur when fixating a single object ahead of the observer, such as another person.

Predicting what effect fixating another person would have on balance control during locomotion is thus difficult. However, some evidence can be taken from standing experiments. These typically show improvements to postural control when fixating a single near target in relation to the background. The extra parallax cues are thought to provide ‘richer’ retinal information to make postural adjustments against (for a review see [4]). Therefore, it is feasible that the parallax caused by fixating a standing person (whilst the observer is walking) could maintain or improve balance in the observer when compared to no person being present. On the other hand, if the person being observed walked perpendicular to the observer’s heading direction, a smooth pursuit would be needed to track them. Thus, retinal flow would consist of a combination of radial expansion from forward progression, and horizontal flow from the eye rotation [14]. Similar to our previous experiment [5], this would resemble a curved movement with a shifting focus of expansion [14]. Although there are compensatory mechanisms against retinal image motion during smooth pursuits to maintain perceptual stability [6,15], these are imperfect. For instance, there have been documented declines in motion sensitivity [16], and temporal contrast sensitivity to moving stimuli [17]. Ultimately, the altered flow could lead to less accurate visual detection of self-motion, and this could cause a decrease in balance control despite the parallax cues which would be present.

If tracking a walking person is shown to decrease balance control, it could have important implications in older adults. Older adults have been shown to have a reduced ability to decouple retinal flow caused by external motion from that caused by self-motion, potentially due to somatosensory processing declines [18]. Further, this has been shown to decrease stability during locomotion [19]. Therefore, if older adults are less able to process retinal flow during the smooth pursuit to track a walking person, it could lead to a bigger decrease in stability when compared to young adults. Moreover, although our previous laboratory investigation showed a similar decrease to balance control in young and older adults tracking a 2D target, the older adults were already exhibiting lower baseline stability. This is typical in healthy older populations. Any further decrease to balance control caused by tracking a person, regardless of comparison to young adults, would thus be undesirable.

Therefore, the present investigation assessed balance control during walking in young and older adults during free gaze, and when visually fixating or tracking a standing or walking person in a real-world environment. Balance was characterised by ML Sacrum acceleration dispersion. It was hypothesised: 1) Visually fixating a standing person would maintain or improve balance control due to more information from parallax; 2) balance would be decreased when the observed person was walking owing to altered retinal flow patterns; 3) the decreased balance caused by tracking the person would be more profound in the older adults, and the older adults would exhibit less baseline stability throughout testing.

2. Methodology

Participants

Ten young (mean ± SD: age: 23.6 ± 3.4 years, height: 1.68 ± 5.8 m, mass: 69.0 ± 9.9 kg) and 10 older (mean ± SD: age: 71.0 ± 5.5 years, height: 161.2 ± 5.5 m, mass: 63.9 ± 10.3 kg) healthy females participated in the investigation. The older adults were interviewed by telephone to determine eligibility and adhered to inclusion criteria previously outlined [9]. In brief, they had no known musculoskeletal or neurophysiological conditions which could negatively affect balance control during walking. The participants had an uncorrected visual acuity of ≥20/100 and were able to ambulate in the community without visual correction. The participants were also free from convergence insufficiency. Although this is not a typical problem in older adults [20], it could have affected their ability to focus on the stimuli. The investigation was carried out in accordance with the University of Cumbria’s recommendations and guidelines for research involving human subjects, and all procedures, information to the participants, and participant consent forms, were approved by the University of Cumbria Research Committee. All participants gave written informed consent in accordance with the Declaration of Helsinki.

Equipment

Testing was carried out on a flat walkway in an everyday use waiting room (Fig. 1). The walkway consisted of a 2.5 m entry area, which has previously been shown as adequate for older adults to reach a steady-state velocity [21], a 4 m data capture area where balance characteristics were assessed, and a 1 m exit area. Sliding doors, controlled by the researcher, concealed the waiting room from the participants when they were at the start of the walkway. A member of the research team (actor) would be absent from or standing or walking within a standardised actor area at the far end of the waiting room (Fig. 2, see experimental protocol). A custom-made contact mat was used to send a signal to a display which informed the actor when to begin walking and in which direction (also see experimental protocol). Four inertial measurement units (IMUs: Opal, APDM, Portland, Oregon) measured accelerations of the centre front head, sacrum, and left and right ankle anatomical land marks of each participant. Participants wore eye tracking glasses (Tobii Glasses 2 Eye Tracker, Tobii Technology, Danderyd, Sweden) which have a one-point calibration procedure, and autoparallax and slippage compensation allowing for persistent calibration throughout each trial.

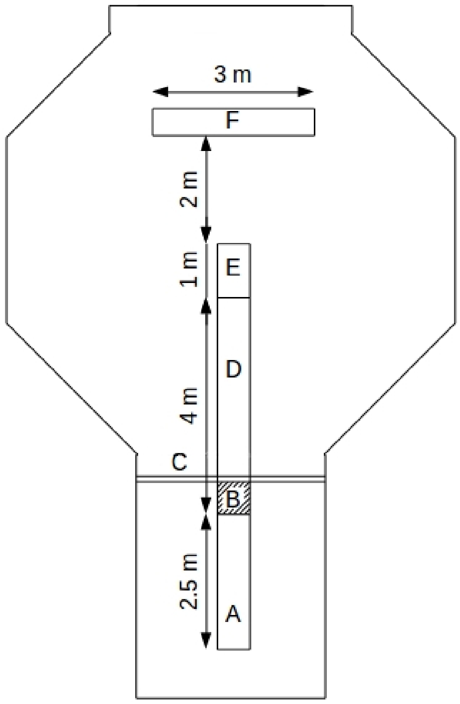

Figure 1. A schematic diagram of the experimental environment. The walkway into the waiting room consists of entry area (A); contact mat (B); sliding doors (C); data collection area (D); exit area (E); pedestrian area (F). All distances are to scale. Note that the observer walkway was not visually marked out and only verbal instructions were given to instruct the participants to stop walking.

Figure 2. Example of a participant’s point of view whilst walking in the waiting room taken from the eye tracking camera. The stationary actor is present in this condition. The red circle on the actor represents a gaze fixation.

Experimental protocol

The sliding doors were shut before each trial and then opened signalling the trial to commence. The participants then walked straight into the room at a self-selected pace until verbally instructed to stop when they reached the exit area. Three conditions were implemented: free gaze (FREE), stationary actor (STAT), and walking actor (WALK). For FREE, the waiting room was void of the actor. For STAT, the actor stood stationary in the centre of the participant's field of vision. For WALK, on the first heel strike on entering the data capture area, the contact mat (beginning at the start of the data capture area and ending 30 cm along the walkway) sent a signal to a laptop out of view of the participant which informed the actor to walk 1.5 m horizontally across the participant's field of vision. The direction was random on each trial. During FREE, the participants were given no instructions where to look. During STAT and WALK, they were informed to look at the actor at all times, and if the actor moved, to track them with their eyes only making sure not to rotate or tilt their heads. The 1.5 m threshold corresponded to 12º of visual angle relative to the participants while they were at the start of the data capture area, and 26º at the end. During STAT and WALK, the actor was present on door opening and was thus visible to the participants at the start of the walkway. However, prior to door opening, the participants were blinded to the conditions in the room.

Five trials for each condition (FREE, STAT and WALK) were completed. The conditions were randomly assorted and segregated into 3 blocks of 5 trials. There was a 30 s rest period between each trial, and a 2-5 min rest period between each block of 5 trials.

Data analysis

Raw data from the IMU devices were exported and analysed offline (Scipy, Scientific Computing Tools for Python). Raw data were filtered with a phase-corrected low-pass Butterworth filter (10Hz cuttoff). Heel strikes and mid-stance phases were determined using validated methods previously described in detail [22,23]. All data were truncated to the first right heel strike upon entering the data capture area, and the third left stride midstance period. Standard deviation (SD) of linear Sacrum acceleration in the participants' ML direction (aligned to the relevant axis of the IMU) then defined sacrum acceleration dispersion, which characterised balance control.

Walking speed was calculated as a function of time and total distance covered. Distance covered was defined as the total of 2 stride lengths between the 3 right foot locations at each midstance period. The right foot locations were calculated using the methods of Rebula et al. [23]. In short, the

Opal proprietary Kalman filter yields a time varying IMU orientation estimate in the global coordinate system, with an arbitrary home location corresponding to the first midstance period irrespective of positioning of the IMU on the ankle. The orientation time series was used to transform the IMU's acceleration trace into the global reference frame by removing the gravity vector. The acceleration trace was then integrated forward between each known zero velocity instant (defined as each midstance period) using the trapezoidal rule to yield a zero velocity updated global velocity trace. The IMU's trajectory in space was then calculated by integrating (also trapezoidal rule) the corrected velocity trace between each zero velocity instant. Principal component analysis was used to fit a line in 3D between the three midstance locations (minimising the distance between the line and each point) which defined the local heading direction. The distance between each footfall location along the heading direction then defined stride length.

To ensure the participants followed instructions, SD of head rotations about the yaw axis obtained from Opal proprietary orientation estimates were calculated, in addition to gaze coordinates [5]. In a modification to the previous gaze analysis [5], a pre-trained histogram of orientated gradients combined with a linear support vector machine model (OpenCV, computer vision library) was used to automatically identify the actor and record their coordinates on the exported 2D video frames, which were subsequently compared to those of the gaze coordinates. The centroid inside the bounding box surrounding the actor was used as a tracking point, which corresponds roughly to the centre of mass of the actor. Root mean square (RMS) of gaze subtracted from the actor coordinates then defined RMS gaze error, and Pearson's correlation coefficients between the gaze and actor coordinates defined the strength of relationship between both timeseries.

Statistical analysis

The mean/median of the 5 trials for each participant in each condition was used for statistical analysis of the relevant outcome measure depending on normal or non-normal distribution of the raw data. Normality of the aggregated data was then confirmed for Sacrum SD, Walking speed and Gaze error RMS, but not for Head rotation SD or correlation coefficients between the gaze and actor coordinates. Condition (3 × visual scenes) and age (young and older) were considered as 2 independent factors. The effect of these factors on Sacrum SD, and Walking speed, were examined with a 2 way (condition × age) mixed analysis of variance (ANOVA). The same model was applied to examine RMS gaze error, but with only STAT and WALK considered. Robust mixed ANOVAs based on trimmed means [24] were used to examine Head rotation SD and correlation coefficients between the gaze and actor coordinates. Post-hoc analyses were *t*-tests with Bonferroni corrections. Finally, where significant differences were found ($p \leq 0.05$), Hedges' g_{av} effect sizes were calculated

[25]. Common indicative thresholds for effect sizes are small (0.2), medium (0.5) and large (0.8). Statistical analyses were performed with the R software package.

3. Results

Sacrum SD in the ML direction is shown in Fig 3. Sacrum SD showed a main effect of condition ($F_{2,36}$=8.585, p<0.001). Post-hoc comparisons revealed larger Sacrum SD during STAT (p=0.003, g_{av}=0.19) and WALK (p=0.027, g_{av}=0.16) compared to FREE. Sacrum SD showed no main effect of age or interaction effect between condition and age.

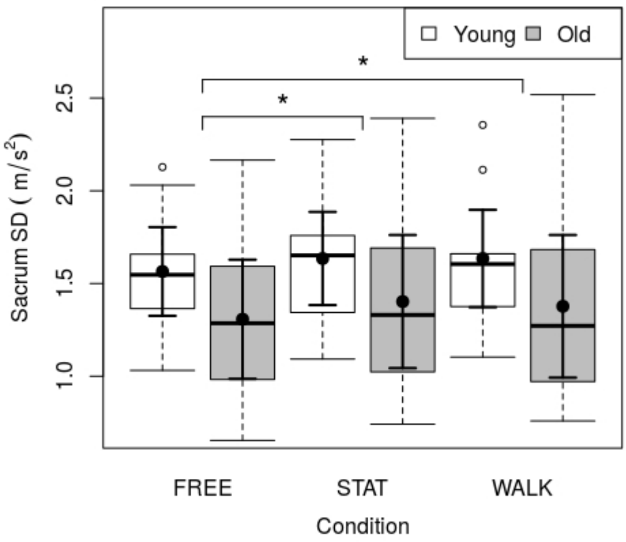

Figure 3. Sacrum SD in the ML direction in young (n=10) and older (n=10) females during different eye movement conditions. FREE: free gaze; STAT: stationary actor; WALK: walking actor. Data are displayed as means and 95% confidence intervals in bold dots and bars, and medians and lower and upper quartiles with Tukey style whiskers (outliers plotted separately). *Significant difference between conditions.

Walking speed is shown in Fig 4. Walking speed showed evidence of a main effect of age ($F_{1,18}$=4.325, p=0.052), with a reduction in the older adults compared to the younger adults. Walking speed showed no main effect of condition, or any interaction effect between condition and age.

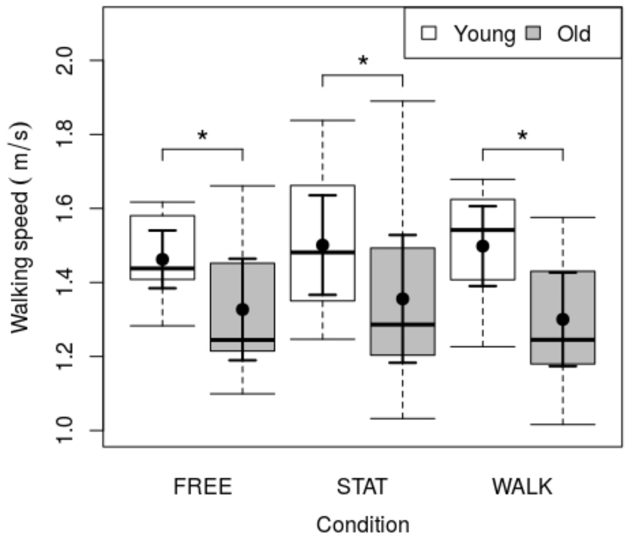

Figure 4. Walking speed in young (n=10) and older (n=10) females during different eye movement conditions. FREE: free gaze; STAT: stationary actor; WALK: walking actor. Data are displayed as means and 95% confidence intervals in bold dots and bars, and medians and lower and upper quartiles with Tukey style whiskers (outliers plotted separately). *Significant difference between age groups.

Head rotation SD is shown in Table 1. Head rotation SD showed no main effect of condition or age, or any interaction effect between condition and age. RMS gaze error and the correlation coefficients between gaze and actor coordinates are shown in Table 2. RMS gaze error and the correlation coefficients (all strong) showed no main effects of condition or age, or any interaction effects between condition and age. This suggests the participants followed instructions and tracked the actor with their eyes whilst refraining from head rotations.

Table 1. Head rotation SD about the yaw axis in young (*n*=10) and older (*n*=10) females during different eye movement conditions. FREE: free gaze; STAT: stationary actor; WALK: walking actor. Data are displayed as means ± SD.

	Head rotation SD (°)	
Condition	**Young**	**Older**
FREE	3.17±2.10	4.91±4.26
STAT	2.64±1.67	3.77±2.02
WALK	2.82±1.15	3.69±1.51

Table 2. RMS gaze error and Correlation coefficients between gaze and actor coordinates in young (*n*=10) and older (*n*=10) females during different eye movement conditions. STAT: stationary actor; WALK: walking actor. Data are displayed as means ± SD.

	RMS gaze error (a.u.)		**Correlation coefficients (*r*)**	
Condition	**Young**	**Older**	**Young**	**Older**
STAT	2.10±0.49	1.87±0.50	0.92±0.17	0.96±0.08
WALK	2.19±0.50	1.97±0.60	0.94±0.05	0.92±0.11

4. Discussion

The present results show a reduction in balance control whilst visually fixating or tracking another person as opposed to free gaze in young and older adults. In contrast to our first 2 hypotheses, there was a similar decrease to balance control when the person being observed was standing compared to walking. There were no differences in gaze errors between conditions or ages, and the correlations between the gaze and actor coordinates were all strong. It can thus be assumed that the participants followed instruction and averted their gaze to the actor. There were also no changes in walking speed between conditions, and so alterations to walking speed could not have altered ML trunk acceleration. Therefore, it seems to be that the underlying mechanisms responsible for the decreased balance control had a similar magnitude of effect in both conditions.

One potential explanation is that the act of constraining vision to the actor inherently altered balance characteristics as opposed to free gaze. That is, it might have hindered the gathering of visuospatial information useful for balance control. Doi et al. [26], for example, demonstrated increased ML trunk acceleration in healthy older adults reading from an earth-fixed display when compared to free gaze [26]. However, they also found a reduction in walking speed, which was thought to be associated with the 'dual task' nature of walking and reading. The present results do not show this. Moreover, merely constraining vision to a fixed location ahead of the observer has previously been shown not to alter gait characteristics when compared to free gaze in older adults [27]. Therefore, it is unlikely that the present results can be explained by either simply constraining vision, or by dual task effects.

From another perspective, gazing real-world biological motion adds a social layer when compared to inanimate stimuli. Varlet et al. [28], for example, showed that 2 participants who were in each other's field of view exhibited unintentional coupling of variables associated with control of stance when performing a visual tracking task. This phenomenon, termed 'interpersonal coordination', has been shown in a variety of conditions [29]. In the present experiment, as the actor walked across the participants' field of view (corresponding to the participants' ML plane), any coupling could have contributed to the increase in ML trunk acceleration. However, unintentional coupling would not explain the decreased balance control when the actor was stationary.

A more likely explanation pertains to a change in the way parallax flow is processed during locomotion compared to standing. That is, we predicted parallax caused by fixating the standing person would maintain or improve balance control, since balance during quiet stance improves when fixating near objects [4]. However, quiet stance is associated with slow and small head movements. During locomotion, the gait cycle would induce bigger and more abrupt movements of the head [30]. In the present experiment, this would have caused the image of the background behind the actor (which would have been subject to defocus blur) to shift up and down and side to side with greater magnitude and more abruptly on the retina. Therefore, it seems that this dynamic retinal flow was more difficult to interpret, and equally so to the flow caused by tracking the walking person.

With regard to ageing effects, the older adults walked more slowly throughout testing compared to the younger adults. This is typical, and the values fall in line with previous literature [31]. Importantly, the older adults exhibited similar ML acceleration dispersion compared to the younger adults despite the reduced walking speed. It is known that ML trunk acceleration is dependent on walking speed [32]. Therefore, the older adults were relatively more unstable than the younger adults. This agrees with our previous findings [5] and supports part of our final hypothesis.

Despite the lower baseline stability, averting gaze to the actor did not cause a bigger reduction to balance control in the older adults when compared to the young adults, which was unexpected. One possible explanation is that the older adults simply processed retinal flow during the visual tasks as effectively as the young participants. This might not be surprising considering other older populations have been shown to exhibit resistance to visual motion perception ageing effects due to compensatory mechanisms [33]. The present older participants were also healthy and could all ambulate within the community without visual correction. They can thus be considered as a relatively healthy sample of the wider older population.

An alternative explanation relates to rigidity. In their review, Young and Mark Williams [34] suggest older adults may prioritise visual stability during visual search behaviours by adopting a more rigid posture. This is because older adults can have a reduced ability to initiate stabilising head movements [35]. In the present experiment, averting gaze to the actor might have caused a similar stiffening effect. Hence, the older adults might have been working harder to maintain a rigid posture to facilitate the ocular movements, and this led to attenuated ML trunk acceleration. In a similar vein, an increase in anxiety about performing the visual tasks could have also contributed to a stiffer postural response. For example, Eikema et al. [36] linked anxiety levels to an increase in postural stiffness during a visual target avoidance task. Indeed, increased anxiety has often been shown to generate a more rigid body position in older adults [34]. To shed light on these potential mechanisms, it would be necessary to incorporate more measurement techniques. However, it should be noted that the present experiment attempted to reduce the amount of equipment utilised, thus maximising the real-world element of the research.

There was no ageing effect for the visual parameters of RMS gaze error and correlation coefficients between gaze and actor coordinates. During locomotion, the accuracy of the visual system has been shown to change for saccadic eye movements but not for smooth pursuits in older adults [37], so this might not be unexpected. However, the eye tracking equipment used in the present investigation is not sensitive to fine grained metrics, such as latencies – it was mainly intended to ensure that the participants were following instructions.

In conclusion, the present results show a reduction in balance control in young and older adults when fixating or tracking another person as opposed to free gaze. This was likely related to altered retinal flow. The lack of an ageing effect from the visual tasks might indicate the older adults adopted a more rigid posture to facilitate visual stability. However, further research is needed to confirm this notion. Because the older adults were already exhibiting a lower baseline stability, the further decrease caused by gazing the actor was undesirable. The small increase in sacrum acceleration dispersion may also warrant further investigation in those at a greater risk of falling, such as those with ocular or vestibular dysfunction.

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