Association between somatosensory, visual and vestibular contributions to postural control, reactive balance capacity and healthy ageing in older women

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ABSTRACT

We investigated the biological systems involved in maintaining equilibrium during unstable and perturbed conditions in 39 healthy older women and estimated the annual difference in performance across the older age spectrum using regression. The largest annual difference in equilibrium occurred when the somatosensory system received inaccurate feedback and visual input was removed. With age, weight distribution became asymmetric at the onset of backwards perturbations, possibly in preparation for executing a stepping strategy. When one sensory system was challenged, postural responses were stable suggesting other systems compensated. When multiple sensory systems were challenged, significant differences in postural control emerged with age.

Keywords

Newcas

1. INTRODUCTION

No single biological system is responsible for maintaining balance. Thus, maintaining postural control necessitates the ability to accurately detect sensory stimuli, interpret the information and execute adequate responses (Baloh et al., 1994; Horak, Shupert, & Mirka, 1989). Postural sway is calculated using an 'inverted pendulum model' which assumes that the difference between the centre of mass (CoM) and the centre of pressure (CoP) is proportional to the horizontal acceleration of the body (Gage, Winter, Frank, & Adkin, 2004; Winter, 1995). Greater magnitudes of sway may be an early indication of reduced postural control and could inform falls risk in susceptible individuals (Lajoie & Gallagher, 2004; Melzer, Benjuya, & Kaplanski, 2004).

Previous research has explored postural responses across a wide age distribution (7-81 years) (Peterka & Black, 1990). While this work helps us gain an understanding of the contributions of sensory input between young and old age groups, we are unable to discern subtle nuances in postural strategies for those at greatest risk of falling - the older adults. Evidence suggests that changes in balance performance are progressive, with greater impairments observed in the oldest old (>80 years) (Camicioli, Panzer, & Kaye, 1997). A heightened falls risk in older adults is well known, with 30-50% of all older adults aged >65 years falling at least once every year (Berg, Alessio, Mills, & Tong, 1997; Soriano, DeCherrie, & Thomas, 2007). Therefore, establishing the factors that contribute to falls in this group, and identifying the specific time-course of these changes, is important. Such insight would allow more appropriate recommendations for screening older adults for falls risk and/or devising targeted physical therapies.

Poor postural control can have serious repercussions on an individual's ability to perform many essential activities of daily living by adversely affecting falls risk, mobility, independence and quality of life. Age-related deteriorations in functional capacity may be more pronounced in older women, resulting from their increased life expectancy (Barford, Dorling, Smith, & Shaw, 2006) and greater risk of falling compared with older men (Blake et al., 1988). Falls-related injuries in older women are often more severe and the associated costs are reportedly 2-3 times higher (Stevens, Corso, Finkelstein, &

Miller, 2006). The aim of this study was to evaluate the association between older age and postural control during stable and unstable conditions whereby somatosensory, visual and vestibular contributions to balance were manipulated and following postural perturbations. It was anticipated that postural sway would increase with age and task complexity and that the ability to respond to postural perturbations would reduce with older age.

2. METHODS

2.1 Participants

For this cross-sectional study design, participants were recruited across a broad range of older age to estimate the relationship between postural control and ageing. Inclusion criteria stipulated participants must be: community-dwelling; able to walk independently; stand independently for 10-minutes; and have good (corrected) vision. Participants were excluded if they had any cardiovascular, musculoskeletal or neurological diseases; a history of falls within the previous year; or were taking five or more different medications at the time of this research (polypharmacy). Thirty-nine females were recruited in partnership with the local NHS Trust and through advertisements. Participant characteristics were as follows: mean (SD) age 71.9(7.2)years, age range 60-83years; height 163.1(6.6)cm; mass 71.4(13.1)kg. All participants gave written informed consent and attended a single session for balance assessment. The study was approved by the NHS Local Research Ethics Committee (Ref:08-H1305-91). Further information regarding the functional capacity of this sample has been published previously (Alcock, O'Brien, & Vanicek, 2015).

2.2 Protocol

Participants wore a safety harness and took part in two tests on the NeuroCom® SMART Equitest® balance system (Natus Medical Inc.,Pleasonton, CA, USA) whilst wearing their own comfortable flat-soled shoes, in order to retain ecological validity. Participants were asked to stand upright and still during all tests with their arms at their sides and were told what to expect prior to each test, as per the manufacturer's instructions (NeuroCom® International, 2004). The Sensory Organization test (SOT)

was completed first, followed by the Motor Control test (MCT). The SOT challenges the sensory and perceptual systems responsible for maintaining balance, namely the somatosensory, visual and vestibular systems. The SOT computes several variables, including the *Equilibrium* (% sway amplitude limit) and *Strategy* (% contribution of ankle vs. hip strategy) *scores* and *Sensory analysis* (sensory system reliance). The MCT protocol is designed to evaluate the ability to respond to unexpected disturbances to balance caused by a backwards and forwards translation of the support surface (i.e., reactive balance control). Variables of interest included response latency and weight symmetry at onset of the perturbation.

2.2.1 Sensory Organization Test (SOT)

The SOT is comprised of varying conditions whereby the sway-referenced support surface and visual surround create inaccurate somatosensory and visual information, respectively. The contribution of each system to balance maintenance is consequently isolated and stressed during six conditions. Conditions are performed in a standardised order and each is made up of three, 20-second trials. The six conditions are as follows: Condition 1 presents a normal balance condition (eyes open); Condition 2 is completed without visual feedback (eyes closed); in Condition 3 visual feedback is inaccurate (sway-referenced surround). Condition 4 presents inaccurate somatosensory information (sway-referenced support surface); in Condition 5 visual input is removed (eyes closed) and somatosensory cues are inaccurate (sway-referenced support); finally, in Condition 6 eyes are open and visual and somatosensory cues are inaccurate (sway-referenced surround and support). The support surface is stable in the Conditions 1-3 and unstable (sway-referenced) in Conditions 4-6.

2.2.2 Motor Control Test (MCT)

The support surface produces three consecutive backwards translations of incremental magnitude (small, medium and large), which are then repeated in the forwards direction. These were performed in the standardised order. The small translations are considered a threshold stimulus, serving as a familiarisation, and were not analysed. The dual force plate system (each plate 230x460mm) incorporates four transducers mounted symmetrically to measure vertical force and a fifth transducer

mounted below the central pin joint to measure shear force parallel to the ground. Forces are measured for the left and right foot separately.

2.3 Data Analysis

Postural outcomes analysed for the Sensory Organisation Test and Motor Control Test were computed by the NeuroCom® software.

2.3.1 Sensory Organization Test (SOT)

The average of the three trials collected for each condition was analysed (Cohen, Heaton, Congdon, & Jenkins, 1996). The safety harness prevents the participant from actually falling. However, if they stumbled or took a step, that trial was marked as a zero and included in the average of the three trials for that condition.

The *Equilibrium score* reflects the angular difference between the maximal measured anterior-posterior displacement of the CoG and the maximal theoretical sway limit (12.5°), normalised to 100, with 100% representing complete stability.

The *Equilibrium Composite score* represents the scores obtained across all six conditions, thus providing a general observation of overall balance. A score of 100 represents complete stability.

Strategy score indicates the contribution of the hip and/or ankle strategies to maintaining balance. The scores sit on a continuum and are expressed as a percentage, with 100% and 0% indicating total reliance on an ankle or hip strategy, respectively.

The *Sensory analysis ratio* expresses the reliance on each of the contributory systems to maintaining balance and are explained in Table 1. Low scores indicate the person's inability to use information from a specific sensory system to control balance effectively.

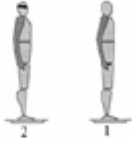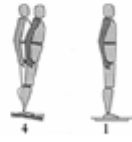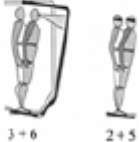**Table 1** The four sensory ratios explained for the Sensory Organisation Test

RATIO	CONDITIONS	EQUATION	SIGNIFICANCE
SOMATOSENSORY (SOM)		$\dfrac{\text{CONDITION 2}}{\text{CONDITION 1}}$	Indicates how a person uses somatosensory input in the absence of visual information LOW SCORES = Person makes poor use of somatosensory input
VISUAL (VIS)		$\dfrac{\text{CONDITION 4}}{\text{CONDITION 1}}$	Indicates the person's ability to use visual information to maintain balance LOW SCORES = Person makes poor use of visual information
VESTIBULAR (VEST)		$\dfrac{\text{CONDITION 5}}{\text{CONDITION 1}}$	Indicates how a person uses vestibular information when there is no visual input and somatosensory information is inaccurate LOW SCORES = Person makes poor use of vestibular cues, or vestibular cues are unavailable
VISUAL PREFERENCE (PREF)		$\dfrac{\text{CONDITION 3 + 6}}{\text{CONDITION 2 + 5}}$	Indicates how much a person relies on visual information even when that information is inaccurate LOW SCORES = Person relies on visual cues even when they are inaccurate

Image courtesy of Natus Medical Incorporated

2.3.2 Motor control test (MCT)

Medium and large perturbations (horizontal translations) were analysed in backwards and then forwards directions. Translation duration (msec) and magnitude (inches) were scaled to individuals' height. Medium translations were 300ms in duration and the amplitude was set at 1.25*(height/72); large translations were 400ms and set at 1.25*(height/72) (NeuroCom® International, 2004). *Response latency* (msec) reflects the time between the initiation of force plate translation and sudden change in

the position of the centre of force by each foot on the force plate, termed active force response. *Weight symmetry* indicates whether the participant shared weight evenly between the right and left legs prior to a support surface translation. A score of 100 indicated equal weight symmetry, whereas scores of 0 and 200 represented total weight on left and right sides, respectively.

2.4 Statistical Analysis

Pearson's correlations quantified the relationship between age and postural control outcomes. Linearity of the variables was assessed via visual inspection of the x/y scatterplots. Linear regressions models were developed with balance outcomes to estimate the annual differences in postural control with older age. Explained variance (R^2%), slope coefficients (B) and associated significance ($P \le .050$) were reported. Significant results for the gradient of the regression line (B) indicate data were significantly different from 0 and that the predictor (age) made a significant contribution to the model compared to relying on the group mean alone. Ten outliers were found from plotting the standardised residuals (>3SD). For completeness, models including and excluding outliers are presented within the Tables and the footnotes of the Table, respectively. Correlations were considered fair (0.25-0.49), moderate (0.50-0.74) and strong (0.75-1.00) (Portney & Watkins, 2009).

3. RESULTS

3.1 Sensory Organization Test

A loss of balance (LoB) occurred when a participant took a step or touched the visual surround, but did not actually fall. In Condition 3, two women experienced one LoB and in Condition 5, sixteen women experienced between 1-3 losses of balance. During Condition 6, 27 women experienced between 1-3 losses of balance none of which caused any harm or injury. Overall, participants at the older end of the age spectrum experienced more LoBs (>3 each).

3.1.1 Equilibrium scores

Upon visual inspection, *Equilibrium scores* equilibrium data during normal quiet standing (Condition 1) were almost unaffected by increases in age (all participants scored ≥85%, sample mean (SD) 95.0 (2.4)) (Figure 1). Significant yearly differences in postural stability were observed in Conditions 5 and 6 when inaccurate information was relayed to the somatosensory system (sway-referenced support) and visual input was removed (Condition 5). Age accounted for a small portion of variance in these conditions (R^2=21 % and 11%, respectively P≤.037) and upper bound confidence intervals signified larger decreases in postural stability compared with the corresponding confidence interval for Condition 6. This negative correlation indicates that participants made poorer use of somatosensory information with age when visual input was removed.

3.1.2 Equilibrium Composite score

Bivariate correlations revealed that age was negatively associated with the *Equilibrium Composite score* (r=-.43, P≤.010). Linear regression revealed that 18% of the variance observed could be attributed to age. Point estimates revealed significant yearly losses in postural equilibrium when using the weighted average of the six conditions as an overall assessment (B=-.632, P=.007).
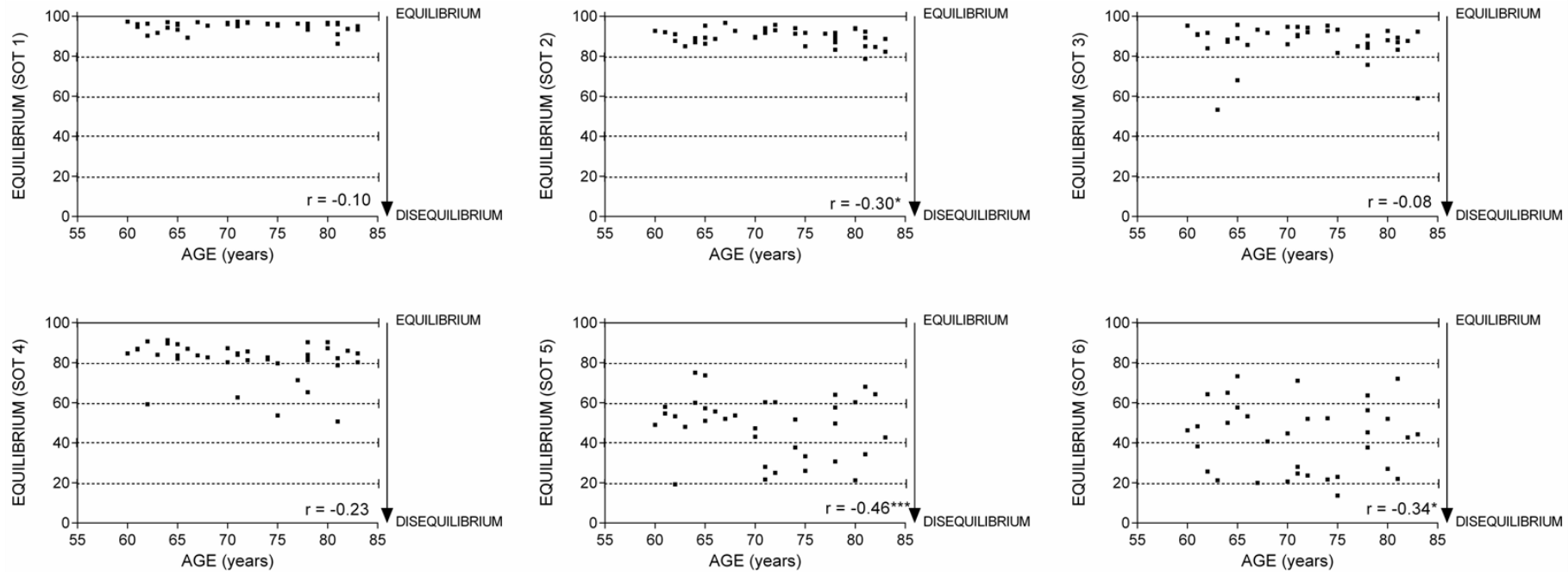
Figure 1 Relationships (r) between age (years) and Equilibrium score (%) for each of the six conditions of the Sensory Organization Test (SOT 1 - 6). Each data point represents the average for each individual participant

* denotes correlations are significant at the .05 level (2-tailed), ** denotes correlations are significant at the .001 level (2-tailed)

Table 2 Explained variance (R^2) and slope coefficient B (point estimate) data for the Equilibrium and Strategy scores of the Sensory Organisation Test

SOT CONDITION		1	2	3	4	5	6	EQ COMP
EQUILIBRIUM (EQ) SCORES				[1]				
MEAN (SD)		95.0 (2.4)	89.8 (4.0)	87.1 (9.2)	81.0 (9.7)	41.5 (21.4)	36.1 (22.1)	65.5 (10.7)
RANGE		86-97	79-97	53-96	51-91	0-75	0-73	40-80
r (SOT$_{COND}$ x Age)		-0.10	-0.30*	-0.08	-0.23	-0.46***	-0.34*	-0.43**
R^2			9 %	9 %	5 %	21 %	11 %	18 %
SLOPE COEFFICIENT (B)			-0.166	-0.198	-0.310	-1.374	-1.005	-0.632
SIGNIFICANCE			.061	.070	.164	.003	.037	.007
95% CONFIDENCE INTERVAL	LOWER BOUND	-	-	-	-	-2.251	-1.948	-1.080
	UPPER BOUND	-	-	-	-	-0.498	-0.063	-0.184
STRATEGY SCORES				[2]	[3]	[4]	[5]	
MEAN (SD)		97.5 (1.5)	95.5 (2.4)	94.4 (3.9)	85.8 (5.5)	71.4 (11.8)	72.2 (11.0)	
RANGE		93-100	90-99	81-99	62-94	49-98	35-92	
r (SOT$_{COND}$ x Age)			-0.18	-0.04	-0.29*	0.11	0.09	
R^2			3 %	0 %	8 %	1 %	1 %	
SLOPE COEFFICIENT (B)			-0.061	-0.017	-0.155	0.150	0.121	
SIGNIFICANCE			.269	.828	.079	.524	.587	
95% CONFIDENCE INTERVAL	LOWER BOUND	-	-	-	-	-	-	
	UPPER BOUND	-	-	-	-	-	-	

* denotes correlations are significant at the 0.05 level (2-tailed), ** denotes correlations are significant at the 0.01 level (2-tailed), *** denotes correlations are significant at the 0.001 level (2-tailed), □ denotes non-significant trends (.05 < p ≤ .10)

[1] CONDITION 3 EQ R^2 = 1 %, SLOPE COEFFICIENT (B) = -.104, p = .621
[2] CONDITION 3 ST R^2 = 1 %, SLOPE COEFFICIENT (B) = .047, p = .602
[3] CONDITION 4 ST R^2 = 0 %, SLOPE COEFFICIENT (B) = -.022, p = .862
[4] CONDITION 5 ST R^2 = 0 %, SLOPE COEFFICIENT (B) = .025, p = .929
[5] CONDITION 6 ST R^2 = 4 %, SLOPE COEFFICIENT (B) = .307, p = .227

3.1.3 Strategy scores

During stable Conditions 1-3, all participants relied predominantly on an ankle strategy to maintain balance (*Strategy score* of ≥80%), regardless of differences in age, and no significant relationships were identified. When somatosensory input was inaccurate (Condition 4), a significant correlation revealed increased involvement from the hip muscles (r=-.29, P≤.050). The progressive increase in postural demands across SOT conditions, and especially across unstable (sway-referenced support) conditions, was corroborated by the fact that the ankle strategy alone was insufficient to maintain balance and participants relied more on a combination of the ankle and hip strategies during unstable conditions when somatosensory and visual input were inaccurate and/or removed (Conditions 5 and 6).

3.1.4 Sensory analysis

Relationships between each of the sensory ratios and age are presented in Table 3. Five women (aged 77-83 years) experienced a LoB in all trials of Conditions 5 and 6, and therefore a vestibular preference ratio could not be calculated (n=34).

The somatosensory, visual and vestibular ratios were negatively correlated with age but only the somatosensory relationship reached statistical significance (r=-.34, P≤.050). Age explained the greatest portion of variance for the somatosensory ratio (R^2=11%) with only minimal variance explained by age for the visual, vestibular or visual preference ratios.

Table 3 Explained variance (R^2) and slope coefficient B (point estimate) data for the Sensory ratios calculated from the Sensory Organisation Test

SENSORY RATIO		SOM	VIS	VEST	VIS PREF [1]
MEAN (SD)		0.95 (0.03)	0.85 (0.10)	0.50 (0.16)	0.93 (0.16)
RANGE		0.87 – 1.00	0.56 – 0.97	0.21 – 0.80	0.50 – 1.45
r (SENSORY RATIO x Age)		-0.34*	-0.22	-0.23	0.11
R^2		11%	5%	5%	2%
SLOPE COEFFICIENT (B)		-0.001	-0.003	-0.005	0.003
SIGNIFICANCE		.037	.183	.190	.410
95% CONFIDENCE INTERVAL	LOWER BOUND	-0.003			
	UPPER BOUND	0.000			

SOM: Somatosensory ratio, VIS: Visual ratio, VEST: Vestibular ratio, VIS PREF: Visual preference,

* denotes correlation is significant at p ≤ .05 (2-tailed)

[1] VISUAL PREFERENCE = R^2 1%, SLOPE COEFFICIENT (B) = .002, p = .517

3.2 Motor Control Test

There were no LoB recorded during the MCT.

3.2.1 Response latency

Latency times were positively correlated with age and only the relationship between the latency and age recorded during the medium backwards translations was significant (r=.40, $P{\leq}.050$). Similarly, regression analysis revealed increased response latency with older age across all conditions, however only slope coefficients for the medium translations were significant (R²=16%, B=.761, $P=.013$, Table 4).

3.2.2 Weight symmetry

Analysis of correlations between weight symmetry and age revealed small positive relationships for all conditions indicating that with advancing age, and the onset of a perturbation, participants distributed their weight more towards either the left or the right leg (Table 5). Only the correlation between age and weight symmetry during medium backwards translations was significant ($r=.33$, $P{\leq}.050$). Similarly, regression analysis resulted in significant point estimates for this condition only, demonstrating that these annual differences were significantly different to zero.

Table 4 Explained variance (R^2) and slope coefficient B (point estimate) data for the response latency (ms) and strength of the force response recorded during the Motor Control Test (MCT)

MCT TRANSLATION			BACKWARDS		FORWARDS	
		MEDIUM	LARGE	MEDIUM	LARGE
RESPONSE LATENCY (ms)					
MEAN (SD)		138.16 (13.6)	135.77 (13.6)	141.67 (17.3)	135.26 (14.0)
RANGE		120.0 – 185.0	115.0 – 175.0	110.0 – 195.0	110.0 – 175.0
r (MCT$_{COND}$ x Age)		0.40*	0.19	0.32□	0.32□
R^2		16 %	4 %	10 %	10 %
SLOPE COEFFICIENT (B)		0.761	0.355	0.757	0.613
SIGNIFICANCE		0.013	0.253	0.051	0.051
95% CONFIDENCE INTERVAL	LOWER BOUND	0.173			
	UPPER BOUND	1.349			

* denotes correlations are significant at the 0.05 level (2-tailed), □ denotes non-significant trends (.05 < p ≤ .10)

Table 5 Explained variance (R^2) and slope coefficient B (point estimate) data for the between-limb weight symmetry recorded during the Motor Control Test

MCT TRANSLATION		BACKWARDS		FORWARDS	
		MEDIUM	LARGE	MEDIUM	LARGE
WEIGHT SYMMETRY					
MEAN (SD)		99.97 (12.2)	100.5 (12.3)	99.36 (12.5)	98.95 (12.0)
RANGE		56.0 – 118.0	54.0 – 120.0	50.0 – 117.0	55.0 – 119.0
r (MCT$_{COND}$ x Age)		0.33*	0.29	0.28	0.25
R^2 (%)		11 % [1]	8 % [2]	7 % [3]	5 % [4]
SLOPE COEFFICIENT (B)		0.281	0.247	0.232	0.194
SIGNIFICANCE		.044	.097□	.111	.186
95% CONFIDENCE INTERVAL	LOWER BOUND	0.008			
	UPPER BOUND	0.554			

* denotes statistical significance $p \le .05$. □ denotes non-significant trends (.05 < $p \le$ .10). Statistical analyses were conducted to determine whether, with advancing older age, participants loaded one limb more than another and therefore for regression purposes only, limb loading was quantified irrespective of left or right limb loading

[1] MEDIUM BACKWARDS R^2 = 9 %, SLOPE COEFFICIENT (B) = .360, p = .072
[2] LARGE BACKWARDS R2 = 9 %, SLOPE COEFFICIENT (B) = .360, p = .072
[3] MEDIUM FORWARDS R^2 = 8 %, SLOPE COEFFICIENT (B) = .359, p = .087
[4] LARGE FORWARDS R^2 = 6 %, SLOPE COEFFICIENT (B) = .306, p = .121

4 DISCUSSION

We examined the contributions of the somatosensory, visual and vestibular systems in maintaining postural control and analysed postural responses to balance perturbations caused by a moving platform. Our research makes an important contribution to the existing body of research by highlighting that postural control in healthy older women is compromised under conditions where somatosensory input is inaccurate and visual information is restricted, and that these differences manifest with age. We have shown that significant annual reductions in postural stability exist with age, due to increased sway in the most challenging (unstable) conditions.

4.1 Sensory Organization Test: Contribution of sensory systems for balance control

Our results are in agreement with previous work using age-grouped data that found reduced deviations in postural sway during stable conditions (Conditions 1 and 2), and larger deviations during the more challenging, unstable sway-referenced support surface conditions (Conditions 5 and 6) in the older groups (70-79 years and 80-89 years) compared with the young (18-44 years) and middle-aged (45-69 years) groups (Cohen et al., 1996). When only one sensory system was challenged (i.e. visual/ vestibular/ somatosensory in Conditions 1-4) postural responses were stable across the older age spectrum, suggesting that the systems receiving accurate information were able to compensate. However, when multiple sensory systems were challenged (i.e., Conditions 5 and 6), differences in postural control began to emerge across the older age spectrum.

We found that age was most strongly correlated with utilisation of somatosensory feedback, compared to other sensory systems. On the whole, participants demonstrated poorer use of vestibular cues (vestibular ratio) compared with somatosensory cues. This implies that even when the vestibular system may have encountered age-related deterioration, a combination of good (corrected) visual and adequate somatosensory systems can negate reduced vestibular functioning with age. This concurs with early studies citing that vision plays an important role in maintaining balance and may compensate for the reduced abilities of other systems (Nashner & Berthoz, 1978; Whipple, Wolfson, Derby, Singh, & Tobin, 1993). The older women in this study demonstrated a high reliance on visual input. Inaccurate

or no vision increased their postural sway as the vestibular system could not correct sufficiently, indicating that the ability to utilise vestibular information deteriorates with older age. To account for this deterioration, regular eye checks and appropriate visual correction are essential with advancing age to visually guide locomotion within complex environments.

During stable Conditions 1-3, all participants relied predominantly on an ankle strategy to manage postural control regardless of differences in age. However, *Strategy scores* recorded when somatosensory information was inaccurate (Condition 4) were significantly correlated with increased involvement from the hip muscles. This suggests that the balance testing protocol using CDP offered adequate sensitivity to detect the smaller annual differences in balance strategies associated with healthy ageing. When postural challenges were the greatest (i.e., Conditions 5 and 6), participants diverted some of these demands towards the larger muscles of the hip joint to maintain upright stance. Reduced ankle strength and mobility occurs with older age (Vandervoort & McComas, 1986) and consequently locomotor demands are also diverted proximally to offset the age-related strength reductions at the ankle during level gait (Alcock, Vanicek, & O'Brien, 2013; DeVita & Hortobagyi, 2000; Judge, Davis, & Ounpuu, 1996; Lewis & Ferris, 2008). We propose that strength training of the ankle joint and associated musculature may improve the ankle balance strategy ensuring older adults are better equipped to respond to balance disturbances.

4.2 Motor Control Test: Responses to postural perturbations

The ability to recover balance following an external perturbation requires that a postural response is executed with sufficient speed and strength. Our findings have revealed few differences between the ability to respond to the backwards and forwards translations with age. Latency times for each of the conditions were positively correlated with age but only the relationship between age and latency during the medium backwards translations was significant (r= .40, $P \leq .05$). Similarly, regression analysis revealed increases in response latency with older age across all conditions, however only slope coefficients for the medium backwards translations were significant and this is consistent with previous work (Cohen et al., 1996; Hageman, Leibowitz, & Blanke, 1995). Response latencies during each of

the conditions ranged from 110-195ms, which were longer than successful postural responses reported previously (Horak & Nashner, 1986). It is worth noting that participants were informed prior to the MCT that they would experience a perturbation to balance and as such the MCT may underestimate the motor response executed. In the event of a genuine balance disturbance, the perturbation may be multidirectional and unknown to the individual and this would likely increase the motor planning complexity of the situation. Moreover, the medium backward translations were completed first after the threshold stimulus (small) translations and a lack of significant association with age in the other conditions may be a result of task familiarity and response modification.

Our findings revealed small positive relationships for all MCT conditions indicating that, with advancing age, participants distributed their weight more towards one side (left or right). This small shift in weight distribution prior to the perturbation may be an anticipatory strategy, where balance is prioritised by compensating for the increasing reaction times associated with older age. Accordingly, these actions may help to prepare for initiating a stepping strategy to recover balance if it became seriously compromised. Similar strategies have recently been observed in older adults, where elderly fallers prolonged their anticipatory postural adjustment during a choice stepping reaction time test compared to elderly non-fallers (Tisserand, Robert, Chabaud, Bonnefoy, & Cheze, 2016). These authors also postulated that reaction time may be indicative of fear of falling or other muscular limitations.

4.3 Study considerations and future work

Participants completed postural assessments wearing their own shoes. The proprioceptive feedback generated between the foot and support surface likely plays an important role in the neural relay of response instructions. Footwear and sole thickness influences somatosensory feedback (Menz, 2002) and COP calculations. We considered that should a postural disturbance occur within a person's typical environment, it is likely that they would have been wearing footwear and therefore the balance responses recorded should represent that of a real event. Equally, perturbations to balance that occur in daily life may be multidirectional, and this is a limitation of the Equitest system which perturbs balance in the anterior-posterior direction only.

There are some important implications arising from this work. As postural control worsened under conditions of inaccurate somatosensory input and absent or inaccurate visual input, falls prevention programmes for older adults could benefit from incorporating targeted exercises performed on compliant surfaces and under eyes closed conditions. The effects of these recommendations would need to be evaluated through an intervention study that is outside the scope of the current research. Future studies should also confirm the current findings longitudinally across a larger age range and with larger cohorts to identify the optimum point of change for targeting balance interventions. Moreover, establishing objective SOT and MCT thresholds to identify low, moderate and high falls risk in older adults would be worthwhile.

5 CONCLUSION

The ability to maintain an upright posture underpins many tasks associated with daily life. In the presence of inaccurate somatosensory information and inaccurate visual feedback during more challenging balance conditions, healthy older women demonstrated reduced postural control, with impaired use of vestibular input, and greater reliance on a hip strategy with older age. With advancing older age, body weight became distributed more asymmetrically, suggesting the adoption of an anticipatory postural adjustment for enhanced dynamic stability following the onset of a balance perturbation. This may have been in preparation for executing a stepping strategy to compensate for the increased response latency with age.

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