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Assessing age-related balance deterioration: Visual or mechanical tasks?

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ABSTRACT

Background: Mediolateral balance assessment (MELBA) comprises tracking of predictable and unpredictable targets moving at increasing frequencies, using centre-of-mass feedback. The mediolateral-balance-assessment was shown to be sensitive to subtle age-related balance deterioration. However, it has been suggested that performance during ground-level tasks can be more sensitive to balance deterioration.

Methods: we developed a modified mediolateral-balance-assessment using tracking of surface translations with comparable waveforms (mechanical mediolateral-balance-assessment) to compare age sensitivity of the visual and mechanical mediolateral-balance-assessment, 15 older adults (68 SD 5 yr) and 12 young adults (30 SD 4 yr) performed both tasks. Phase-shift and gain between the CoM and either the visual target or the surface displacement for the visual and the mechanical mediolateral-balance-assessment, respectively, were calculated. To identify differences in tracking strategies between the visual and mechanical mediolateral-balance-assessment, phase-shift between trunk and leg angles was calculated.

Findings: Overall, older adults performed worse than young across the predictable and unpredictable tracking and visual and mechanical tasks. Of all mediolateral-balance-assessment performance descriptors, a significant interaction between age and task (visual or mechanical) was only found for the mean phase-shift. Post-hoc comparisons revealed significant age differences in the visual but not in the mechanical mediolateral-balance-assessment. Significant differences in tracking strategies were found between visual and mechanical mediolateral-balance-assessment with a greater decoupling of trunk and legs during the mechanical than the visual mediolateral-balance-assessment.

Interpretation: the visual mediolateral-balance-assessment was more sensitive to age-related balance deterioration than the mechanical mediolateral-balance-assessment, possibly because visual tracking elicits motor strategies that are more affected by ageing.

1. Introduction

Identifying the presence and underlying mechanisms of balance control impairments with ageing is essential to better target interventions for fall prevention in the elderly (Tinetti et al., 1988). Evidence indicates that impairments of balance control in the mediolateral (ML) direction can cause inadequate balance responses and consequent falls in institutionalized and healthy older adults undergoing daily-life perturbations (Hilliard et al., 2008; Maki et al., 1994; Robinovitch et al., 2013). This has been associated with incorrect weight-shifting or inadequate transfer of weight between limbs, which has been found to be the most common cause of falls among elderly in residential care facilities (Robinovitch et al., 2013). In order to quantify weight-shifting abilities in older adults, we previously developed the mediolateral balance assessment (MELBA), which uses predictable and unpredictable tracking tasks with centre-of-mass (CoM) feedback on performance (Cofré Lizama et al., 2014). Whereas the performance on the predictable target can inform about the physical capabilities (strength and power) of the balance control system, unpredictable target tracking additionally challenges the sensorimotor integration process (Cofré Lizama et al., 2013).

Although reliable and sensitive to ageing (Cofré Lizama et al., 2013; Cofré Lizama et al., 2014), MELBA tracking tasks involve voluntary mediolateral weight-shifting driven by visual inputs and do not

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consider challenges by external perturbations. The latter is relevant when navigating in daily-life environments (Winter, 1995). External perturbations can be applied by perturbing the CoM position (e.g. pushing or pulling) or by perturbing the base of support (e.g. surface rotation or translation) (Rogers and Mille, 2003). Further, it has been suggested that perturbations of the base of support may be more sensitive to age-related deterioration of balance than perturbations of the CoM (Horak et al., 1997; Mansfield and Maki, 2009; Pasma et al., 2014).

The balance control system relies on a complex sensorimotor integration process that weights visual, vestibular and proprioceptive information to execute motor responses according to the environmental challenges (Peterka, 2002). Therefore, it is unlikely that a single assessment tool can measure the indemnity of all potential balance responses. Nevertheless, it is reasonable to believe that those tests that challenge the main underlying mechanisms during common daily-life activities are the most sensitive to balance deterioration. There is a vast literature that has identified increased visual reliance and proprioceptive deterioration as potential sources of balance deterioration in the elderly (Poulain and Giraudet, 2008; Shaffer and Harrison, 2007; Yeh et al., 2014). Hence, comparing older adults' performance with that in the young adults under two similar tasks that challenge these systems can help determining what type of the test may be the most suitable to identify subtle changes in balance control in older adults population.

The aim of this study was to determine whether performance in the original MELBA (visual-MELBA) or a modified MELBA using tracking of surface translations (mechanical MELBA) with slightly modified waverforms is more sensitive to balance deterioration in community-dwelling older adults. Although Arvin et al. (2016) used the mechanical tracking in older adults to determine the effects of strength and proprioception, no comparison to young adults was performed (Arvin et al., 2016). Further, other studies by Cofré Lizama et al. (2013, 2014 and 2015a, b) have only used visual tracking tasks (Cofré Lizama et al., 2013, 2015a; Cofré Lizama et al., 2014; Cofré Lizama et al., 2015b). Since MELBA is intended to be further developed as an instrumented clinical tool, this study is a crucial step in determining whether efforts to translate MELBA into a sensitive clinical tool should be directed towards a visual tracking task with videogame-like software or a mechanical tracking with ground perturbation type of hardware-software. Furthermore, to our knowledge, this is the first study comparing young and older adults balance performance during mechanical and visual tracking tasks. Based on previous literature that has shown an increased visual reliance accompanied or compensatory to proprioceptive deterioration and an increased challenge of the latter system during surface translations (Arvin et al., 2016), we hypothesized that the mechanical MELBA may be more sensitive to ageing than the originally proposed visual tracking task.

2. Methods

2.1. Participants

Fifteen community-dwelling older adults (11 females, 4 males; mean age 68.3, with a standard deviation (SD) of 4.8 years; mean height 165.6 SD 7.0 cm; mean mass 68.1 SD 12.6 kg) and twelve young adults (7 females, 5 males; mean age [29.9 SD 3.6 years]; mean height [169.7 SD 9.2 cm]; mean mass [67.5 SD 6.9 kg]) participated in this study. The inclusion criteria for the older participants were: a) older than 64 y/o; b) Mini-mental State Examination score > 25; c) no diagnosis of osteoporosis, Parkinson's disease, neuropathic diabetes, vestibular or other neurological disorders, d) no history of falls within last year; e) no history of joint replacements; f) no history of heart surgery and/or heart attack; g) able to stand and walk for at least 20 min (self-reported), and h) no use of beta blockers or anti-depressive medication. The inclusion criteria for the young adults were: a) between 18 and 35 y/o; b) no diagnosis of arthritis, vestibular or other neurological disorders; c) no history of joint(s) replacement(s); d) able to stand and walk for > 20 min; e) no history of heart attack; f) no beta-blockers or anti depressive prescription; and g) no musculoskeletal pain at the moment of assessment.

The local ethics committee of KU Leuven University approved the procedure in accordance with the declaration of Helsinki. After a verbal explanation of the study, participants signed a consent form before participation.

2.2. Instrumentation

A computer-assisted rehabilitation environment (CAREN) system (Motekforce Link, Amsterdam, The Netherlands) was used to implement the visual and mechanical tasks (visual and mechanical MELBA, respectively). The system uses a 6-camera VICON system and Nexus software (Oxford Metrics, Oxford, UK) sampling at 100 samples/s. Marker's kinematic data were then streamed to D-flow 3.18.0 software (Motekforce Link, Amsterdam, The Netherlands) to calculate CoM position online. The D-flow software was also used to produce the visual target and display the CoM on a 2 × 1.5 m screen in front of the subject during the visual MELBA, and to produce the signal that controlled the moveable platform for the mechanical MELBA (100 samples/s).

2.3. Experimental design

The mediolateral balance assessment task (MELBA) used consists of tracking a target with the whole-body CoM (Cofré Lizama et al., 2014). Each participant performed two visual MELBA tasks including predictable and unpredictable target trajectories. In addition, each participant also performed two mechanical MELBA tasks using similar predictable and unpredictable waveforms provoking ML translations. For both tasks, subjects stood with their arms crossed; while the distance between feet was standardized at 11% of body height with a 14° stance angle between the longitudinal axes of both feet (Cofré Lizama et al., 2014). This normalization procedure allowed participants to position their feet within the values of normal stance (McIlroy and Maki, 1997) as well as minimizing the effects of stance width on lower limb neuromechanical responses (Bingham et al., 2011).

The *predictable target* signal was constructed using 2 blocks of 20 s, 1 block of 10 s, and 13 blocks of 5 s, each composed by one sine wave, which increased in frequency from 0.1 to 1.6 Hz in steps of 0.1 Hz. The total ML CoM- tracking time for this target signal was 115 s.

The *unpredictable target* signal was constructed using 2 blocks of 20 s, 2 blocks of 8 s, 2 block of 6 s, and 4 blocks of 4 s, each composed by sine waves separated by 0.1 Hz, which increased in frequency from 0.1 to 1.6 Hz in steps of 0.1 Hz. The total ML CoM-tracking time for this target signal was 114 s. A pseudorandom phase-shift between sine waves between −1 to 1 period was introduced in order to avoid predictability.

In the *visual MELBA*, the target (white sphere of 11 cm diameter) and participants' CoM position (red sphere of 9 cm diameter) were projected on a screen (2 × 1.5 m size), in front of them. The projected target moved sinusoidally in ML direction while its movement frequency increased over time. The target maximum side-to-side displacement was normalized to 50% of stance width; this normalization has been previously shown to make the test sufficiently challenging to obtain sensitive results (Cofré Lizama et al., 2014). The participants were instructed to track the target by ML CoM movement as accurately as possible (Fig. 1). To do so, they were instructed to move their entire body as a single inverted pendulum in the frontal plane for as long as possible. Although, the latter is the most efficient strategy to displace the CoM in the ML direction, some degree of trunk/legs decoupling may occur as a strategy to change the contribution of musculature acting in the frontal plane (Cofré Lizama et al., 2015a). Six trials (three trials for each predictable and unpredictable target) of visual MELBA were randomly performed by each participant.

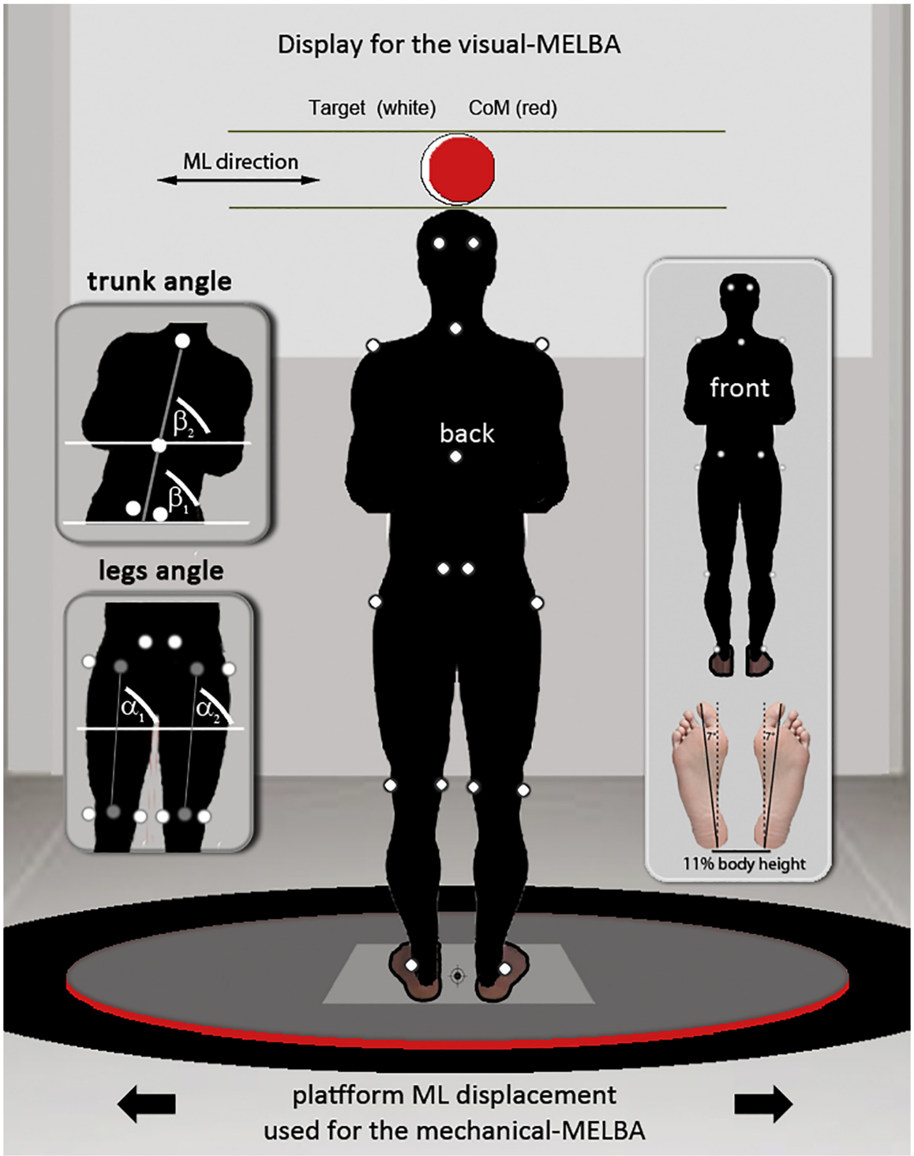

Fig. 1. Setup on the CAREN system for the visual and mechanical MELBA. Display in front of the subject presents the target (white sphere) and CoM feedback (red sphere). For the mechanical MELBA the circular platform was displaced in the ML direction (display off) using a similar waveform than for the visual targets. Insertions on the left show the angles used to determine the overall leg and trunk angles. Insertions on right show the feet position during trials and front markers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In the *mechanical MELBA*, the participants were asked to stand on a movable CAREN platform (Motekforce Link, Amsterdam, The Netherlands), while wearing a safety harness attached to the ceiling. The setup was the same as in Fig. 1, except that the representation of the CoM and the visual target were not projected and the target was the mediolaterally moving platform. Subjects were instructed to follow the platform movement with their CoM by standing in an as vertical as possible position and were not allowed to step. The target signal was constructed with the same frequency changes and amplitude normalization as the visual-MELBA. However, actual maximum amplitude achieved by the platform decreased by 2% to 64% over the range from 0.4 Hz to 1.6 Hz (e.g. 9% at 0.7 Hz and 30% at 1 Hz) (Appendix B). Although the software (D-flow) application written for this experiment requested the CAREN system to move the platform using the same input wave as for the visual MELBA, the system automatically scaled the amplitudes to fit the system's capabilities (maximum acceleration of the platform was 5.9 ms^{-2}). Note that to obtain same amplitudes for the low and high frequencies a more powerful motor would be needed as the system needs to rapidly accelerate/decelerate the platform. Six trials (three trials for each predictable and unpredictable target) of mechanical MELBA were randomly performed by each participant. In addition, all participants performed one static postural trial of 3 s for construction of anatomical coordinate systems.

For both tasks, visual and mechanical, a safety harness attached to the ceiling was worn by the participants. The tension was enough to allow the necessary trunk displacement and yet minimizing any potential haptic feedback.

2.4. Data collection

Twenty-one retro-reflective markers were bilaterally attached on the lateral malleoli, femoral epicondyles, greater trochanters, anterior and posterior superior iliac crests, acromions, as well as on the forehead, clavicle, sternum, C7 and T10 vertebrae spinous processes.

The body CoM was calculated online using a 9-markers frontal plane model (forehead, acromion, anterior-superior iliac spines, lateral femoral epicondyles and lateral malleoli). Sex specific CoM calculations were performed using scaling of anthropometric data and inertial

Table 1
Descriptive statistics for all MELBA tasks (mean (standard deviation; sd)) descriptors (f_{PS}, PS_{mean} and f_G and G_{mean}) and angle strategy (PS_{angle}). Age refers to young and older adults, task refers to the visual and mechanical MELBA tasks and target refers to the predictable and unpredictable target. The significance level ($p < 0.05$) is bolded in main effect (η^2).

		Visual MELBA				Mechanical MELBA											
		Predictable		Unpredictable		Predictable		Unpredictable									
		Mean	SD	Mean	SD	Mean	SD	Mean	SD		Age	Task	Target	Age * task	Age * target	Task * target	Age * task * target
f_{PS}	young	1.08	0.20	0.99	0.20	1.03	0.20	0.88	0.20	p	**< 0.01**	0.70	**< 0.01**	0.23	0.88	0.59	0.71
	older	0.82	0.20	0.72	0.20	0.87	0.20	0.75	0.20	η^2	−0.30	< 0.01	0.34	0.06	< 0.01	0.01	0.01
PS_{mean}	young	−28.00	4.50	−47.20	8.30	−47.80	4.30	−57.60	4.00	p	**< 0.01**	**< 0.01**	**< 0.01**	**0.04**	0.22	**< 0.01**	0.81
	older	−34.60	5.30	−56.00	6.80	−48.60	6.90	−60.60	7.60	η^2	−0.30	−0.76	−0.90	−0.16	−0.06	−0.62	< 0.01
f_G	young	1.06	0.10	1.01	0.20	0.86	0.20	0.86	0.30	p	**0.01**	**0.01**	0.74	0.23	0.30	0.56	0.70
	older	0.82	0.10	0.86	0.10	0.74	0.10	0.79	0.20	η^2	0.23	0.27	0.01	0.05	0.04	0.01	0.01
G_{mean}	young	0.83	0.04	0.51	0.08	0.74	0.17	0.58	0.08	p	0.60	0.45	**< 0.01**	0.96	0.95	**< 0.01**	0.09
	older	0.79	0.05	0.52	0.08	0.75	0.14	0.54	0.08	η^2	0.01	−0.02	0.92	< 0.01	< 0.01	0.40	0.10
PS_{angle}	young	−36.3	36.9	−47.1	26.2	−56.4	25.2	−59.9	21.9	p	0.87	**0.04**	0.26	0.55	0.92	0.54	0.97
	older	−40.8	40.3	−53.3	44.1	−54.0	26.3	−58.5	44.6	η^2	< 0.01	0.18	−0.06	−0.01	< 0.01	0.01	< 0.01

parameters described by De Leva (De Leva, 1996).

For analysis of the movement strategy, the thigh anatomical coordinate system was constructed using the lateral femoral epicondyle and greater trochanter (Fig. 1, insertion). The pelvis was constructed using the left and right anterior-superior and posterior-superior iliac spines (ASIS and PSIS, respectively). The abdomen was constructed using the left and right ASIS, T10, sternum, and C7. And the thorax was constructed using the sternum, T10, clavicle, and C7. Absolute (global) thigh, abdomen and thorax angles relative to the laboratory axis system were calculated based on the International Society of Biomechanics recommendations (Wu et al., 2002). The absolute left and right thigh angles in ML direction were averaged to calculate the leg absolute angle; similarly, the absolute abdomen and thorax angles in ML direction were averaged to calculate the trunk absolute angle (Fig. 1, insertions).

2.5. Data analysis

Balance performance over the frequency ranges of the target signal was defined as the gain of the linear constant coefficient transfer function between body CoM position and target signal, using the Welch algorithm over windows of 0.25 times the length of the target (per block) with 90% overlap between windows. Responsiveness (bandwidth) of the balance control system was assessed in terms of the response delay (PS; in degrees) and amplitude ratio (G) between the CoM and the target for both, the visual and mechanical MELBA. Perfect performance implies a zero degrees PS (no delay) and a gain equal to one (same amplitude) over all frequencies comprised in the target signal. As in our previous studies (Arvin et al., 2016; Cofré Lizama et al., 2014; Cofré Lizama et al., 2015b), the frequencies at which the PS dropped below 90° and gain dropped below 0.5 were determined as the cut-off frequency for phase shift (f_{PS}) and gain (f_G). These performance descriptors indicate the bandwidth of adequate balance control within the task. The average PS (PS_{mean}) and average G (G_{mean}) were also calculated within the bandwidth of 0.1 Hz till f_{PS} and f_G (Appendix A). The 90° threshold was chosen considering that a motor reaction after 0.25 of a cycle means that CoM and target will have an opposite direction during half a cycle, implying that for frequencies above 1.4 Hz a 90° delay will demand reaction times above those exhibited by young adults in clinical tests (> 182 ms) (Lord et al., 2003). A threshold of 0.5 for the gain will demand ≈5 cm CoM displacement when tracking a single sine wave (average ML displacement in MELBA is ≈10 cm). This displacement is similar to the displacement exhibited during walking at relatively normal speed (≈1.2 m/s) and is average between walking at 1.0 m/s (slow) and 1.6 m/s (fast) (Orendurff et al., 2004).

In addition to the four balance descriptors for the MELBA tasks (f_{PS}, PS_{mean} and f_G and G_{mean}) we calculated the phase shift between the leg and trunk angles (PS_{angle}), to characterize differences in motor strategies utilized during the visual and mechanical MELBA. This parameter describes the decoupling of trunk and leg movements, which implies abd/adduction of the legs and trunk lateral bending (frontal plane movements). The legs/trunk decoupling strategy was previously found to occur during the visual task as frequency increases (ankle-to-hip shift) (Cofré Lizama et al., 2015a). The PS_{angle} was calculated for all frequencies present in the target signal and then averaged over the bandwidth of the start point (0.1 Hz) until f_{PS}, which varied according to each subject's visual or mechanical MELBA performance (Cofré Lizama et al., 2015a). PS_{angle} negative values indicate that the trunk segment followed the legs when tracking the target. All data analyses were performed in MATLAB R2012.

2.6. Statistical analysis

All outcomes were averaged over repeated trials. The assumption of normality was checked by Shapiro-Wilks test. Homogeneity of variance was checked using the Levene's test. No violations of these assumptions were found. To test the differences in balance descriptors including f_{PS}, PS_{mean}, f_G, G_{mean}, and PS_{angle} between the mechanical and visual as well as between predictable and unpredictable targets in both age groups, three factor age group (young and old) × task (visual MELBA and mechanical MELBA) × target (predictable and unpredictable) mixed-design analyses of variance (ANOVA) were performed. In case of significant interactions of task or target with age, Independent-Sample *t*-tests were applied to test the age differences for tasks and targets separately. For all analyses, *p*-values < 0.05 were considered significant. All statistical analyses were performed using IBM SPSS statistics 21.0.

3. Results

The analysis of variance yielded a significant main effect of: a) age on f_{PS}, PS_{mean} and f_G; b) task (visual or mechanical) on PS_{mean} and f_G and PS_{angle}; and c) target (predictable or unpredictable) on f_{PS}, PS_{mean} and G_{mean} (Table 1). Most of these results presented a large effect size ($\eta^2 > 0.26$), except for the age effect on f_G ($\eta^2 = 0.23$) and age * task interaction on PS_{mean} ($\eta^2 = 0.16$) for which effect sizes were between medium and large (Miles and Shevlin, 2000). These results indicate that: a) older adults presented a less accurate tracking performance during both tasks and targets than young adults; b) participants from both groups performed worse during the mechanical than during the visual MELBA; and c) tracking of the unpredictable target was less accurate than of the predictable target. There were no interactions of age and predictability, indicating that predictable and unpredictable targets are equally suitable to detect age-related deterioration of balance control. However, a significant age * task interaction effect was found for PS_{mean}. Post-hoc tests showed that for PS_{mean}, age differences occurred when tracking the visual but not the mechanical targets for both targets, predictable and unpredictable (Table 2). No 3-way (age*-task*target) interactions were found for any of the performance descriptors.

Regarding the motor strategy, a main effect of task on PS_{angle} indicated less trunk-leg decoupling during visual compared to mechanical MELBA. PS_{angle} was not affected by age or target, nor by any of the interactions.

4. Discussion

The aim of this study was to determine whether a mechanical MELBA task, in which ML translations of the platform have to be followed, is more sensitive to detect age-related balance deterioration than a visual tracking task. To do so, we used a previously developed test MELBA (Cofré Lizama et al., 2014), which consists of tracking targets with the whole-body CoM. The predictable and unpredictable target trajectories involved in this test assess the responsiveness of the balance control in terms of control bandwidth as defined by f_{PS} and f_G. Our results revealed a significant age effect for all balance descriptors, except averaged gain (G_{mean}). Older adults exhibited a significantly reduced balance control bandwidth (PS_{mean}) compared to young adults during the visual MELBA tasks but not during the mechanical MELBA. This was contrary to our hypothesis and to previous literature suggesting that mechanical perturbations are more challenging, hence, more sensitive to age-related deterioration of balance control (Horak et al., 1997; Mansfield and Maki, 2009; Pasma et al., 2014).

All participants in both groups exhibited a lower performance in the mechanical compared to the visual tasks. A significantly greater trunk-legs decoupling was also found in the mechanical compared to the visual MELBA. This suggests that mechanical MELBA may impose a greater challenge for the balance control system requiring a change in motor strategy in both age groups to cope with the task (similar change in PS_{angle}). These strategies may involve an increasing use of hip musculature and trunk-legs decoupling, as seen in previous studies using surface perturbations (Arvin et al., 2016; Jilk et al., 2014). We used the average angle phase-shift (PS_{angle}) within PS_{mean} as an overall measure of the strategies utilized during both tasks and both targets. Although is not a conventional measure we believe it adequately reflects tracking strategies and that is not greatly affected by antiphase leg/trunk movements as this may have elicited small CoM displacements incompatible with the demands of the tasks. This analysis was motivated by our previous work comparing CoM and CoP tracking in which we observed an ankle-to-hip strategy shift as frequency increased (Cofré Lizama et al., 2015a).

It is noteworthy, that the lower performance observed in the mechanical compared to the visual MELBA (all participants) may reflect the different sensory sources being challenged to control balance. Whereas for the visual MELBA participants react to a visual stimuli, which works over long neural loops (slow response), the mechanical MELBA may primarily challenge the proprioceptive system over short neural loops (fast response). Furthermore, the age * task interaction showing a lower PS_{mean} for the older adults during the visual MELBA, may indicate that long neural loops using the visual input may be more affected in the control of mediolateral balance with ageing. From this perspective the better performance on the visual compared to the mechanical task may seem paradoxical, but this may be explained to the relatively low frequency content of the signals to be tracked.

Differences in age sensitivity between the visual and mechanical MELBA tests may be associated with differences in the motor strategy used, which involved more decoupling and trunk following legs movements in the mechanical MELBA. This may reflect faster responses of distal musculature as it is closer to the source of proprioceptive inputs. Further, it has been suggested that elderly use proprioception rather than visual and vestibular cues for balance control (Wiesmeier et al., 2015), which may offer them a relative advantage when performing mechanical compared to visual MELBA. It is important to note, however, that other studies suggest that older adults rely more on visual than proprioceptive inputs when compared to the young (Poulain and Giraudet, 2008). Although, these studies do not fully support or reject an increased reliance on proprioception since tasks studied (visual and mechanical) are different in comparison with MELBA, they highlight the complexity of sensorimotor integration indifferent contexts.

Balance performance in the older adults, as measured by PS, was significantly lower than in the young during the visual but not the mechanical tasks as shown in the age*task posthoc analysis (Table 2). This suggests that visual MELBA is more sensitive to ML balance deterioration with ageing than the mechanical tasks. A previous study by our group also found a lower control bandwidth during MELBA in older than in young adults and with similar overall performance values (Cofré

Table 2

p-Values for the post-hoc *t*-tests performed over the main effects of age and target (predictable and unpredictable). Significant *p*-values are presented in bold.

			MELBA tasks	
			Visual	Mechanical
Effect of age	f_{PS}	pred	< **0.01**	0.09
		unpred	**0.01**	0.19
	PS_{mean}	pred	< **0.01**	0.74
		unpred	< **0.01**	0.22
	f_G	pred	0.06	0.09
		unpred	0.10	0.47
	G_{mean}	pred	< **0.01**	0.88
		unpred	0.77	0.27
Effect of target	f_{PS}	young	0.17	0.11
		older	0.17	**0.02**
	PS_{mean}	young	< **0.01**	< **0.01**
		older	< **0.01**	< **0.01**
	f_G	young	0.51	0.96
		older	0.53	0.26
	G_{mean}	young	< **0.01**	< **0.01**
		older	< **0.01**	< **0.01**

Lizama et al., 2014). This balance deterioration can partly be attributed to a decreased hip abduction-adduction strength and torque production in older adults population as these muscles are some of the main actuators in the displacement of the CoM in the frontal plane (Arvin et al., 2015; Arvin et al., 2016; Chang et al., 2005; Johnson et al., 2004). However, deterioration of other systems with ageing such as vision and attention, which are highly challenged during visual MELBA, may also have a negative effect on balance control (Maki et al., 2001; Maki and McIlroy, 2007). Other age-related factors such as attention switching delays and cognitive decline, may also explain the significantly lower gains and larger phase-shifts in the older than the young adults, especially in the unpredictable tracking tasks (Cofré Lizama et al., 2013; Cofré Lizama et al., 2014).

Few studies have used surface perturbations to assess balance control in older adults and most of them have used discrete and not continuous perturbations as in the mechanical MELBA (Petro et al., 2017). Furthermore, few studies have used tracking tasks, mechanical or visual, to determine age-related balance changes (Arvin et al., 2016; Cofré Lizama et al., 2014; Sotirakis et al., 2016). Therefore, comparison of our MELBA tasks with previous research using computerized or laboratory assessments of balance in older adults is difficult and perhaps inadequate. However, we believe that MELBA tasks can assess the overall integrity of balance subsystems affected by ageing (sensorimotor processing) making it more ecologically valid than most common computerized tests (Cofré Lizama et al., 2015b). Furthermore, the 2 tasks compared in this study focus on the ML balance control as it is inherently related to weight-shifting ability, which has been shown to be prospectively associated to instability and falls in older adults' population (Hilliard et al., 2008; Maki et al., 1994; Robinovitch et al., 2013; Rogers and Mille, 2003).

Finally, since the visual MELBA showed to be more sensitive to ageing than the mechanical, this highlights its potential use to determine the effects of interventions aimed at maintaining or restoring balance in older adults. Furthermore, due to the different challenges presented by the predictable and unpredictable targets, performance on each of these tasks may help to better target interventions and to determine their specific effects on the balance control system. Further studies will explore the use of inexpensive and portable devices such as infrared depth-cameras (e.g. Microsoft Kinect) to implement MELBA (visual) in clinical settings.

5. Limitations

Although the visual and mechanical target construction was comparable, the maximum amplitude of mechanical MELBA decreased at the highest frequency ranges due to mechanical constraints. Nevertheless, in both groups performance dropped earlier in the mechanical MELBA than in the visual MELBA. Descriptors calculated show that performance dropped at frequencies at which platform displacements (mechanical MELBA) were from 77% to 91% of those in the visual MELBA. Therefore, the drop of amplitude at higher frequencies did not make the mechanical task less challenging than the visual task and still the visual task showed larger differences between age groups.

6. Conclusion

In conclusion, age-related mediolateral balance deterioration was better detected using visual MELBA tasks than mechanical (surface translation) MELBA tasks. Differences in motor strategies underlie age-related performance in the visual MELBA and may reflect slower and less accurate balance responses in the frontal plane in apparently healthy older adults.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clinbiomech.2019.04.012.

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