

# Postural control in elderly subjects participating in balance training

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**Abstract** The changes in postural control in elderly people after an 8-week training course were characterized. Static postural stability was measured during standing on a single force platform first with the eyes open and then with the eyes closed. Body sway was analysed on a force plate in groups of elderly and of young subjects. Half of the elderly subjects then took part in the training course. The posturographic measurements were repeated after the course. The sway in anteroposterior (AP) and mediolateral (ML) directions was subjected to spectral analysis. The frequency spectrum of the platform oscillations was calculated by fast Fourier transformation in the intervals 0.1–0.3, 0.3–1 and 1–3 Hz. It was found that the sway path was longer and the frequency power was higher in the elderly group. The training caused a significant improvement in functional performance, but a significantly longer sway path was observed after the training in the ML direction. The frequency analysis revealed a significantly higher power after 8 weeks without visual control in the ML direction in the training group in the

low and the middle frequency bands. The results suggest that the participants' balance confidence and the control of ML balance improved in response to the training. The higher ML frequency power exhibited after the training may be indicative of a better balance performance. Thus, the increase in the sway path in this age group did not mean a further impairment of the postural control.

**Keywords** Balance · Elderly · Exercise · Training · Postural sway · Frequency

## Introduction

Postural control is the ability to maintain the body's centre of mass over the base of support during quiet standing and movement. It is a perceptual-motor process that includes the sensation of position and motion from the visual, somatosensory and vestibular systems, the processing of the sensory information to determine orientation and movement, and the selection of motor responses that maintains or brings the body into equilibrium (Schmidt 1975). Postural control is affected by alterations in both the sensory and motor systems, including the basal ganglia and the cerebellum, and also the perceptual systems that interpret and transform the incoming sensory information. Accordingly, the vestibular, visual and somatosensory systems, which all undergo changes with aging, may provide a diminished or inappropriate feedback to the postural control centres. Similarly, the muscle effectors may lack the capacity to respond appropriately to disturbances in postural stability (Mazzeo et al. 1998), since declines in skeletal muscle protein mass,

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cross-sectional area and muscle strength occur with advancing age due to the infiltration of fat and connective tissue (Yarasheski 2003). Thus the decreased strength is related to diminished postural control (Buchner et al. 1992; Brown et al. 1995; Wolfson et al. 2005; Onambele et al. 2006), whereas impaired postural control is associated with an increased risk of falling (Campbell et al. 1989; Lord et al. 1994), and elderly fallers have been reported to display a significant decrease in the dynamic strength of the muscles of the knees and ankles as compared with non-fallers (Whiple et al. 1987). Concerning the role of calf muscle-tendon on maintenance balance, it has been suggested that the role of the tendon increases as the base of support decreases, and there is a substantial contribution to changes in torque from intrinsic mechanical ankle stiffness; however, by itself this is insufficient to maintain balance or to control position (Loram and Lakie 2002; Onambele et al. 2006).

The age-related alterations in postural control strategies are also well known. A considerable number of studies have reported on the increase in postural sway with advancing age, with a highly significant positive correlation without marked sex differences (Fujita et al. 2005). Furthermore, centre of pressure (COP) in elderly adults has been found to be located in less safe regions, at the boundaries of the base of support, for greater periods of time as compared with young adults placing them at greater risk of destabilization (Bugnariu and Svestrup 2006). Few investigations have been made of the frequency power spectrum in the elderly (McCleanaghan et al. 1995; Williams et al. 1997). According to Williams et al., elderly subjects exhibited significantly greater frequency dispersion than young adults in the ML direction. Moreover the elderly were characterized by a greater concentration of power at low frequencies in the ML postural forces. The appearance of a low-frequency component exhibited by the elderly suggests the emergence of a slow postural drift or a slow shifting of weight during static standing (Williams et al. 1997).

In recent years, many research labs have designed and tested training programmes with the specific goal of improvement in functional tests, including those of the standing balance in the elderly population (Judge et al. 1993, 1994; Judge 2003; Hue et al. 2004). These results indicated that the improvement occurs as a decreased centre of force displacement, i.e. a better balance control means a smaller postural sway. The exercise programmes that included low-intensity strength and balance training improved the balance and reduced the fall rates as compared with the controls, though the frequency power spectrum was not analysed.

The goals of the present study were to analyse the differences in postural control parameters between young and elderly people, and to explore how a combined training (focusing on the above-mentioned features) can influence the balance parameters (AP, ML sway and frequency power), and functional performance in this specific age group. We hypothesized that the participants would demonstrate better balance control, i.e. smaller postural sway than those who did not take part in the programme.

## Method

### Subjects

Nineteen healthy elderly persons dwelling in a local community were enrolled in the study on a volunteer basis. Subsequently 9 of them were randomized into the training group (3 males, 6 females; age  $79 \pm 1.6$  years; mass  $73 \pm 4.5$  kg; height:  $1.57 \pm 0.023$  m) and the remaining 10 in the control group (3 males, 7 females; age  $76 \pm 1.9$  years; mass  $69 \pm 5.1$  kg; height:  $1.59 \pm 0.029$  m). Eleven healthy students were also investigated as a young control group in order to compare the postural parameters with those of the elderly people (3 males, 8 females; age  $22 \pm 0.4$  years; mass  $58 \pm 2.9$  kg; height:  $1.63 \pm 0.025$  m). All of the elderly subjects were independent and capable of self-care and normal household tasks. All the subjects gave their informed consent prior to participation in the study, which was approved by the local institutional ethics committee.

### Experimental procedure

Static postural stability was measured during standing on a single force platform (Stabilometer, ZWE-PII) for 20-s periods as described earlier (Nagy et al. 2004). The platform allowed measurement of the displacement of the COP (sway path). Signals were amplified and sampled at 16 Hz via an analogue-to-digital converter. Posturography was performed in first with the eyes open (EO) and then with the eyes closed (EC) in a quiet room. During the EO test, the subject looked at a fixed eye-level target at a distance of approximately 2 m. The subject stood barefoot, with the feet positioned side by side with no space between them, with the arms hanging freely at either side and was instructed to minimize postural sway. After the initial balance testing, the training group took part in an 8-week course of combined training (see below “[Training](#)”), while the control group received no

intervention, although the social contact was maintained and they had the opportunity to take part in a next balance training programme on voluntary basis. After the training session, the measurements were repeated for both elderly groups.

To assess the functional mobility of the training participants, the Timed Up & Go (TUG) test was also applied, which means the time it takes for a seated subject to stand, walk 10 ft (3 m), pass around an object, walk back to the chair and sit down again was recorded in seconds. Prior to testing, each subject was informed that the therapist would monitor them closely to minimize the risk of falls.

### Training

The subjects participated in combined training twice a week for 8 weeks in 45-min sessions. The exercise programme included combinations of lower extremity strength and flexibility exercises, static and dynamic balance exercises, and walking as an aerobic activity. In the first 4 weeks, after a short, 5–10 min of warming-up period, the strength and flexibility exercises of the muscles of the trunk and lower extremities were emphasized for 20 min, using a greater base of support such as a lying or sitting position, and the balance and walking (5–10 min) played smaller roles. In the last 4 weeks, this ratio was reversed: we focused on gait and balance exercises (20 min). Dynamic exercises were conducted in standing position gradually decreasing the base of support with and without visual control. In the single-leg stance position the hip muscles were strengthened in a functional way and during gait the direction was changed frequently challenging more the postural control system. The training intensity was gradually increased during the training up to 70% of the maximum heart rate  $[(220 - \text{age in years}) \times 0.7]$  under physiotherapist's instructions.

### Data analysis

The first 4 s of the 20-s time series was regarded as an adaptation period and was discarded from the data analysis after the filtering processes. The data were low-pass filtered at 10 Hz, since most of the power of the signal was <2 Hz (Soames and Atha 1982). The sway path was calculated via the following formula:

$$\text{Sway path} = \sum_{i=1}^{n-1} \sqrt{\{s(i+1) - s(i)\}^2}$$

where  $n$  is the total number of samples,  $i$  is the sample number and  $s$  is the displacement of the COP in the AP

or ML directions. This parameter reflects the amount of activity required to maintain stability.

The sway in both directions was subjected to spectral analysis. The frequency spectrum of the platform oscillations was calculated in the intervals of 0.1–0.3, 0.3–1, 1–3 Hz by fast Fourier transformation based on our earlier work (Nagy et al. 2004).

All of the data were subjected to analysis of variance in order to make comparisons between the groups and the experimental situations, which constituted the independent variables. The post hoc test was the LSD multiple comparisons test. As concerns the TUG test, the Student  $t$  test was used to determine the level of difference. A level of significance of  $P < 0.05$  was adopted throughout the data analysis.

## Results

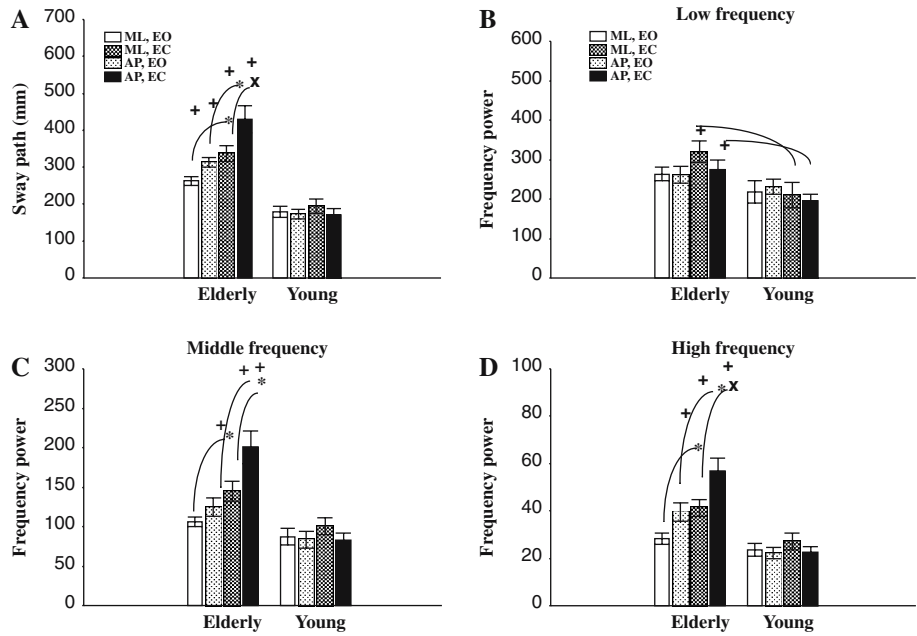
### Age-related changes

There were no significant differences in baseline values between the two elderly groups, and we therefore merged their data before comparison with the young control group.

The sway paths in both directions were significantly higher in the elderly subjects than in the young control group (Fig. 1a). The absence of visual feedback caused a significant increase in both directions in the elderly group, but not in the young control group. The elderly group, but not the young one exhibited a significantly higher sway path in the AP direction than in the ML direction without visual information.

As regards the frequency analysis, there were no significant differences between the two groups in the ML direction with visual control in any frequency band (Fig. 1b–d). In the low-frequency band (0.1–0.3 Hz), there were significant differences between the two groups in the EC condition, i.e. the elderly displayed a higher power in both the ML and the AP direction as compared with the control group (Fig. 1b). Interestingly, in contrast with the higher-frequency bands (see below), the elderly subjects exhibited a slightly higher frequency power in the ML direction with EC than that in the AP direction. In the middle (0.3–1 Hz) and high-frequency bands (1–3 Hz), there were significant differences between the two groups in the AP direction in both visual conditions, and in the ML direction only in the EC condition, i.e. the elderly demonstrated a higher power of sway frequency. While the visual condition did not influence the power in the young control group, the absence of visual control significantly increased the sway power in both directions in the elderly group. As

**Fig. 1** Sway path in both directions (a) and spectral energy in different frequency bands (b, c, d) for the elderly and young control groups. Statistically significant differences ( $P < 0.05$ ) in comparison with the young group: *plus*; and in comparison with the AP direction: *cross*; and in comparison with the open eye condition: *asterisk*



regards the EC condition, there was a significant difference between the two directions for the elderly group, i.e. the AP sway frequency power was significantly higher than the ML power, while the young group did not display these differences (Fig. 1c, d).

The effects of the 8-week training course on the balance parameters

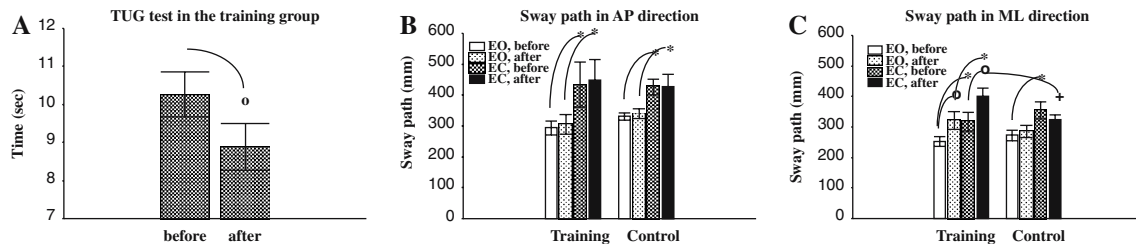
The training caused a significant improvement in the results of the TUG test: the TUG value was  $10.3 \pm 0.6$  s before the training and  $8.9 \pm 0.6$  s after ( $P < 0.05$ ) (Fig. 2a).

As concerns the sway path, the non-training group did not show any significant changes 8 weeks later. For the training group, no effects of the training could be observed in the AP direction. The lack of visual input significantly increased the sway path in both groups in the AP direction before and after 8 weeks (Fig. 2b).

Interesting changes were observed in the ML plane, i.e. the training significantly increased the sway path in both eye conditions.

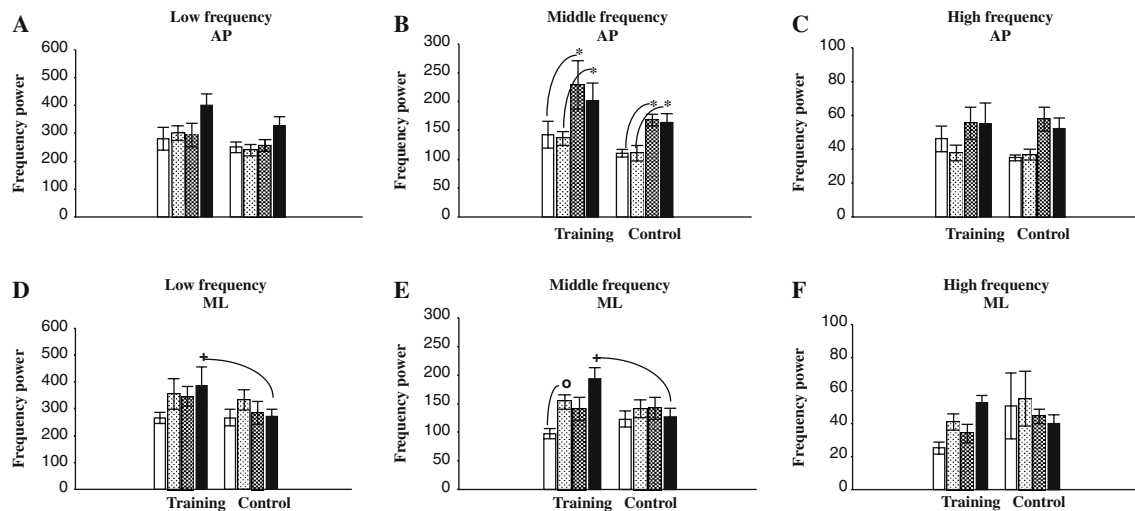
As regards the frequency analysis, the non-training group did not exhibit any significant changes 8 weeks later.

In the training group, the results depended on the frequency band. In the low-frequency band, in the AP directions there was no significant difference between the groups before or after the training (Fig. 3a). The changes appeared in the ML direction: the training group displayed a significantly higher power in the EC condition after 8 weeks (Fig. 3d). In the middle-frequency band, in the AP direction the lack of visual input significantly increased the power in both groups before and after the training period, but the training did not cause any significant effect (Fig. 3b). In the ML direction there was a significant increase in the power in the EO condition after the training, and it was close



**Fig. 2** TUG changes (a) for the elderly training group before and after the training. The effects of the training in the elderly on the sway path in the AP (b) and ML (c) directions for the elderly training and control groups. Statistically significant differences

( $P < 0.05$ ) in comparison with the baseline value: *circle*; in comparison with the non-training group: *plus*; and in comparison with the open eye condition: *asterisk*



**Fig. 3** The effects of the training on the spectral energy at different frequency bands (a–f). Statistically significant differences ( $P < 0.05$ ) in comparison with the non-training group: *plus*; in comparison with the baseline value: *circle*; and in comparison

with the open eye condition: *asterisk*. Abbreviations: *EO* open eye, *EC* closed eye, *ML* mediolateral, *AP* anteroposterior direction

to the significant difference ( $P = 0.059$ ) in the EC condition. Furthermore, the training group showed a significantly higher power than that for the control group in the EC condition after the training (Fig. 3e). In the high-frequency band, there were no significant changes in either the AP or the ML direction after the training, but in the ML direction the training caused a slight increase in frequency power (Fig. 3c, f). Thus, in the ML direction, for the training group, the power was slightly increased in the EC condition in each frequency band, in contrast with the control group, where the opposite tendency could be seen (Fig. 3d–f).

## Discussion

The main findings of the present study were that the elderly who took part in the special training course exhibited a significant improvement in the functional performance test, and significant changes in the posturographic parameters. Thus, the training significantly increased the sway path in the ML direction without visual input. The frequency analysis revealed that the training increased the frequency power without visual control in the ML direction in both the low- and middle-frequency bands.

The significantly greater values of the sway path in both directions and both visual conditions in the elderly as compared with the young agree with the well-known age-related changes in postural control (Buchner et al. 1992; Brown et al. 1995; Collins et al. 1995). Our result is consistent with the findings of Collins et al. (1995): in

a cross-sectional study of healthy subjects, the steady-state behaviour of the open-loop postural control mechanisms—which operates over short-term intervals—is more unstable in older compared with young adults, i.e. the output of the overall system has a greater tendency to move or drift away from a relative equilibrium point, which may be due to a postural control strategy adopted by elderly individuals whereby they increase the level of muscle activity across their lower-limb joints. Loram and Lakie (2002) identified a biphasic, ballistic-like pattern of torque at the ankle ('throw and catch') that is repeatedly used to control the position of the pendulum and the correction of this throw and catch action could be faster in a stiffer unit because force development in an actuator in-series with a compliant unit is inevitably slower than in an actuator in-series with a stiffer unit (Onambele et al. 2006), which may contribute to the increased muscle activity in case of elderly. It is highly relevant to note here that the force output of skeletal muscles contains noise-like fluctuations (De Luca et al. 1982), which increase with muscle activity (Galganski et al. 1993). Increased muscle activity would therefore lead to larger noise-like fluctuations across joints, thereby increasing the amount of short-term postural sway. Similarly, Laughton et al. reported that significantly greater amounts of postural sway and muscle activity were present in the elderly as compared with younger subjects. It is unknown, however, whether increased muscle activity is a contributory factor to increased postural sway, or whether increased muscle activation is a compensation for increased postural sway (Laughton et al. 2003).

The finding was that most changes were observed in the ML direction. In 1985, Nashner and McCollum hypothesized the existence of two discrete strategies that could either be used separately or be combined by the nervous system to produce adaptable control of the horizontal position of the centre of mass in the sagittal plane. Firstly, the ankle strategy repositions the centre of mass by moving the whole body as a single segment-inverted pendulum by production of torque at the ankle. Secondly, and in contrast, the hip strategy moves the body as a double-segment inverted pendulum with counter-phase motion at the ankle and hip. They further suggested that the hip strategy should be observed in situations that limit the effectiveness of ankle torque in producing whole-body motion (e.g. compliant or shortened surfaces) (Nashner and McCollum 1985). In the sagittal plane (AP direction) during quiet standing this stiffness control exists at the ankle plantar flexors, while in the frontal plane (ML direction) by the hip abductors/adductors. In the side-by-side stance, the AP balance is totally under ankle (plantar/dorsiflexor) control, whereas the ML balance is under hip (abductor/adductor) control (Winter et al. 1996; Williams et al. 1997). With respect to EMG activity, the first muscle activated is the proximal tensor fascia latae for lateral translations, whereas the distal muscles are recruited first for AP translations (Henry et al. 1998). Over-reliance on hip joint action has been shown in the elderly when they respond to unexpected postural disturbances (Manchester et al. 1989). Additionally, narrowing the base of support results in greater postural sway in older as compared with younger adults, accompanied by different electromyographic and kinematic patterns. Mixed hip-ankle activation has been observed in the elderly, while young participants accommodate for the increased postural requirements by increasing only the activity of the ankle muscles (Amiridis et al. 2003). Thus, the older subjects apply another strategy for postural control, and these differences might explain the significant changes in the ML direction.

We hypothesized that the participants would demonstrate better balance parameters after the training. In support of this expectation, we detected a significant improvement in the TUG test relating to functional mobility; surprisingly however, both the sway path and the frequency power were increased significantly in the ML direction after the training course.

In recent years, a great number of studies have pointed to lateral instability as a marker of impaired balance control in older persons (Maki and McIlroy 1996, 1997). In an earlier study we found a significantly lower ML power in ironmen trained in extreme strenuous exercises in comparison with healthy normal

control subjects, independently of the visual condition, indicating a higher level of motor control in this direction (Nagy et al. 2004). In the present study the ML balance parameters again appeared to be more sensitive to the effect of training in comparison with the AP parameters. These results are in agreement with the findings of McCleanaghan et al. (1995), i.e. in the AP direction as compared with the ML direction, there are an increased number of alternative strategies that the individual can use to cope with instability, and age differences may be masked by variations in the control strategy adopted.

As noted above, several studies have reported the increased ML sway to be an the indicator of the risk of falling (Maki et al. 1994; Mitchell et al. 1995). However, Laughton et al. (2003) made the noteworthy finding that there were no significant differences in ML sway between the elderly fallers and non-fallers. Our training participants demonstrated a significantly greater ML sway after the training in EC condition in contrast with the control group, which could not be a sign of being more prone to fall than the control group. It is much more likely that the training improved the control of ML balance and/or the participants' balance confidence, and thus the participants became able to control a greater degree of freedom of their hip joints. It is known that an increase in postural sway does not always mean a deterioration of the control mechanisms. In fact, increased sway is not a good predictor of postural instability since many unstable patients, such as patients with Parkinson's disease, show smaller than normal sway in stance (Horak 1997).

Considerable research has demonstrated that vision plays a significant role in balance control: it helps to fix the body's orientation in space (Sheldon 1963) and, when visual information is reduced, the postural sway increases. Furthermore, the sway is increased when vision is removed in healthy older adults (Brooke-Wavell et al. 2002), a result which agrees with our data. Accordingly older people have a greater visual dependence for the control of postural sway relative to the young population. In contrast, Maki et al. (1991) reported that subjects who expressed a fear of falling were found to exhibit a significantly poorer performance, i.e. less sway in blindfolded spontaneous-sway tests.

Frequency analysis of the sway more precisely revealed the changes in postural control. Golomer et al. (1999) suggested that the low-frequency band is linked with visual control, the middle-frequency band is sensitive to vestibular and somatosensory information, and the high-frequencies reflect the proprioceptive control and muscle activity. Our findings support this: the low-frequency band was linked with visual control since the

two age groups did not differ significantly in utilizing the visual information available in this frequency band. One possible factor influencing the control of the upright stance is the threat perceived to personal safety, i.e. balance confidence. Krafczyk et al. (1999) reported that the power spectrum of body sway revealed a difference in the frequency distribution, in the middle (especially between 2.3 and 3.3 Hz) and higher (especially between 4 and 5.3 Hz) frequency ranges; the amplitudes of the power spectrum were greater in patients with phobic postural vertigo, who tended to control their posture with an increased higher-frequency – lower-amplitude body sway, which seems to reflect a change in postural strategy. We also analysed our data with regard to these frequency bands (3–8 Hz) but we did not find significant differences in these bands (data not shown). Carpenter et al. (1999) established that healthy adults adopted a smaller-amplitude and higher-frequency postural sway when standing on a high platform, which was considered as high-threat condition. A stiffening strategy was adopted when individuals stood under this condition involving significant changes in the kinematic, kinetic and EMG variables. These findings suggest that in a situation accompanied by increased postural threat, the central nervous system controls the posture in order to limit the chances of the centre of mass moving outside the base of support (Carpenter et al. 2001). Maki et al. (1994) reported a significantly lower mean frequency power of sway during spontaneous standing in the ML direction in subjects who fell. This finding may lend further support to our suggestion that the higher ML frequency power exhibited after the training indicates a better balance performance.

In agreement with our hypothesis, our results indicated that the combined training exerted a positive effect on the balance performance of the participants, even at this advanced age and it is especially noteworthy that the improvement was in the risky ML direction and without visual control; however, these results may be specific to this type of population.

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