Age-related changes of human balance during quiet stance

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Summary

Certain aspects of balance control change with age, resulting in a slight postural instability. We examined healthy subjects between 20-82 years of age during the quiet stance under static conditions: at stance on a firm surface and/or on a compliant surface, with eyes either open or closed. Body sway was evaluated from centre of foot pressure (CoP) positions during a 50 sec interval. The seven CoP parameters were evaluated to assess quiet stance and were analyzed in three age groups: juniors, middle-aged and seniors.

The regression analysis showed evident increase of body sway over 60 years of age. We found that CoP parameters were significantly different when comparing juniors and seniors in all static conditions. The most sensitive view on postural steadiness during quiet stance was provided by CoP amplitude and velocity in AP direction and root mean square (RMS) of statokinesigram. New physiological ranges of RMS parameter in each condition for each age group of healthy subjects were determined.

Our results showed that CoP data from force platform in quiet stance may indicate small balance impairment due to age. The determined physiological ranges of RMS will be useful for better distinguishing between small postural instability due to aging in contrast to pathological processes in the human postural control.

Introduction

For many elderly subjects, the aging process is inevitably accompanied with restriction of the ability of independent movement and loss of balance (Woollacott 1993). The postural system consists of several sensory systems (somatosensory, visual and vestibular), the motor system and a central integrating control system, which involves complex interactions among multiple neural systems (Horak and MacPherson 1996). These systems are known to be affected by aging and result in an impairment of the ability to maintain stance (Du Pasquier *et al.* 2003). Aging is associated with decline in the function of the sensory systems (Lord and Menz 2000, Baloh *et al.* 2003, Du Pasquier *et al.* 2003, Fransson *et al.* 2004), with diminished muscle strength, decreased muscle volume and mass, loss of muscle fibers, alterations in the motor units (Porter *et al.* 1995), changes in posture (Woodhull-McNeal 1992) and decreased balance control (Wolfson *et al.* 1992).

Adequate postural control depends on the integration of vestibular, somatosensory and visual information of the body motion (Woollacott 1993). Loss of sensitivity in peripheral sensory systems has been reported so frequently in the elderly without diagnosable disease that these losses are widely regarded as a normal consequence of aging (Horak *et al.* 1989). The changes in the somatosensory, vestibular and visual systems have shown significant deterioration in these systems in older adults. Advancing age accompanied with a generalized reduction of the visual system and impaired vision has been associated with postural instability and increased risk of falls (Lord and Menz 2000). Comparison of older and younger subjects showed age-related decreases in vestibular function (Enrietto *et al.* 1999). Adults above 70 years of age have a 40% reduction in sensory cells within the vestibular system (Woollacott 1993). Studies on age-related changes in the somatosensory system reflect a drop in the proprioceptive function of the elderly (Stelmach and Sirica 1986), a reduced vibration sense at the ankles (Manchester *et al.* 1989, Baloh *et al.* 2003) and changes in joint sensation (Stelmach and Sirica 1986, Horak *et al.* 1989).

Age is often accompanied by balance disorders or age-related pathologies, for example osteoarthritis, stroke, Parkinson's and Alzheimer's disease, which hinder independent mobility and lead to postural instability. It is estimated that one third to one half of the population over 65 years presents some problems with balance control, as shown in literature (Hausdorff *et al.* 2001). Since small balance impairment is a consequence of natural aging process, several authors showed that body sway increases with age (Manchester *et al*. 1989, Colledge *et al.* 1994, Fujita *et al.* 2005). For this reason, only a good knowledge of the effect of age on the stability of stance allows to differentiate between physiological aging and the pathologies leading to impaired balance control (Du Pasquier *et al.* 2003).

The ability to maintain stance seems to be optimal at ages ranging from 25 to 60 years (Pyykkö *et al.* 1988). Studies often included comparison of the ability to maintain stance for groups of young and older people only (Manchester *et al*. 1989, Wolfson *et al.* 1992, Prieto *et al*. 1996), or compared middle-aged and elderly people (Fransson *et al*. 2004), or included only a single age group (Lord and Menz 2000). Our intention was to examine and compare the ability to maintain stance in the whole range of human age (juniors, middle-aged and seniors). Because the known fact that elderly have a decreased ability to adapt to altered sensory inputs, we hypothesized that the age-related decrease of ability to maintain quiet stance will be clearer under conditions of reduced sensory information.

The aim of this study was to find age-related CoP parameters of quiet stance in four conditions with graduated reduction of sensory information and to determine an age-related profile of CoP parameters. The obtained data of CoP parameters should allow better distinguishing between small postural instability due to aging in contrast to pathological processes of human balance control.

Methods

The balance during quiet stance of the 81 healthy subjects (23 men and 53 women) of 20 to 82-year-old (mean age 46.93) was tested with their informed consent and approval of the local Ethics Committee. The volunteers were healthy adults without neurological, balance or metabolic disorders, they have not reported falls and they have undergone formal neurological examination. The subjects were divided to three groups: Juniors (J) within the range of 20 - 40 years (34 subjects, 10 men and 24 women, mean age 24.8, mean height 170.9); Middle-aged (M) within the range of 40-60 years (20 subjects, 2 men and 18 women, mean age 52.5, mean height 167.8); Seniors (S) within the range of 60 - 82 years (27 subjects, 11 men and 19 women, mean age 70.7, mean height 167.4).

The postural test consisted of four conditions of quiet stance: stance on a firm surface with eyes open (EO); stance on a firm surface with eyes closed (EC); stance on a foam surface (thickness 10cm) with eyes open (FEO) and stance on a foam surface with eyes closed (FEC). The subjects stood relaxed on the force platform, barefoot, with their heads in a straight-ahead position, their arms along the body, the heels together and feet at an angle of about 30^o open to the front. Before starting each condition, subjects stood in the same central position of the feet related to the force platform. In the anterior-posterior direction a line between bones "*os naviculare*" of the feet was aligned with central axis of platform. During conditions with eyes open subject's eyes were focused on a stationary eye level visual target (a black spot with a diameter 2cm) situated in a white scene in the front at a 2m distance. The duration of each record in each condition was 50 seconds, followed by a short rest period (1-3 minutes).

The body sway was quantified by displacement of the center of foot pressure (CoP) in the anterior-posterior (AP) and in the medial-lateral direction (ML), measured by a force platform. We used custom made force platform with automatic subject's weight normalization. Analog output signals – stabilograms were sampled by frequency of 41 Hz (interval 50s were sampled to 2048 digital points) and recorded on line on PC. The data were analyzed and evaluated in MATLAB program.

The balance control was assessing by seven CoP parameters. The four parameters were amplitude of CoP in AP and ML direction (A_{AP}, A_{ML}), where A=3.92*(SD of CoP) (Hlavacka *et al.* 1990) and velocity of CoP in AP and ML direction (V_{AP}, V_{ML}), was used as

$$V_{AP} = (1/T)*\sum_{n=1}^{N-1}\left|CoP_{AP}[n+1]-CoP_{AP}[n]\right| \qquad \text{(Prieto \textit{et al.} 1996).}$$

The parameters root mean square (RMS), line integral (LI) and total area (TA) were quantified from the CoP path (statokinesigram) including both AP and ML direction (Hlavacka *et al.* 1990).

The normality of distribution of each CoP parameter was examined by using the "Lillie test", which is a modification of the Kolmogorov-Smirnov test. If the analyzed CoP parameters were not normally distributed, the non-parametric Mann Whitney test was used to analyze differences between age groups. If the CoP parameters were normally distributed than the 2-way ANOVA was used to analyze differences between age groups. We used general linear model with repeated measures, the within-subjects factors: were 1) vision (eyes open, eyes closed) and 2) the surface (firm, compliant); the between-subjects factors were three age groups (junior, middle-aged, senior), followed by Bonferroni/Dunn *post-hoc* test. The significance level was set at $p < 0.05$.

Results

The results showed that the postural impairment related to age and sensory deficit was documented by clear increase of CoP parameters values. We have found gradual increase in the CoP parameters due to age (junior, middle-aged and senior age categories) and in conditions with deficit or alteration of sensory information (Fig. 1).

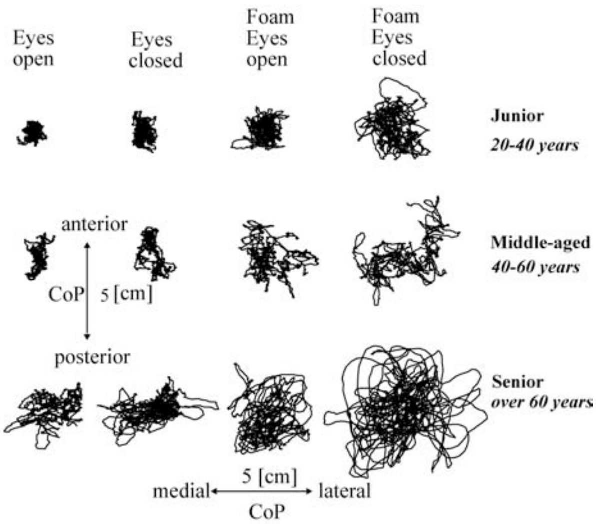

Fig. 1. The statokinesigrams in four tested conditions for typical subjects from three age categories. The increase of CoP displacement is evident with the age in each condition.

The CoP displacements increased during stance with absence of vision or with the alteration of somatosensory input (compliant surface). The paired influence of removed visual and altered somatosensory inputs resulted in greater CoP oscillations. In comparison to juniors and middle-aged, the seniors showed the largest impairment of balance with increases of statokinesigrams in all conditions (Fig. 1). Their CoP responses in AP and ML direction increased mostly in stance on compliant surface with eyes closed.

Detailed analysis of age-related increase of CoP parameters (A_{ML}, A_{AP}, V_{ML}, V_{AP}, RMS, LI and TA) by the polynomial type of regression showed that the gradual increase of body sway characterized by increase of CoP oscillations started around the age of 60 years. The largest increase of body sway was best demonstrated in stance condition on compliant surface with eyes closed by increase of CoP parameters: amplitude (A), velocity (V) in AP direction and by root mean square (RMS) (Fig. 2).

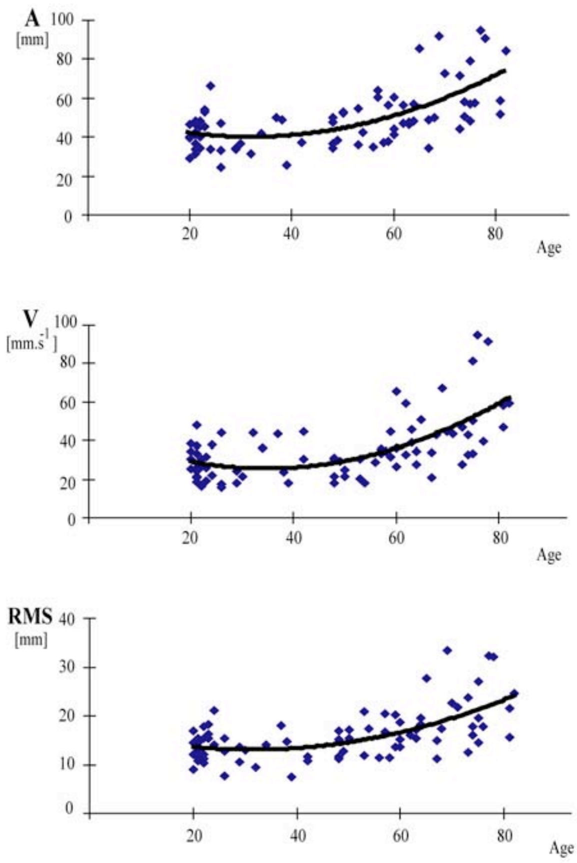

Fig. 2. The impairment of quiet stance with age is clearly indicated by increases of CoP displacement in AP direction amplitude (A), velocity (V) and root mean square (RMS). The figure presents results from condition of stance on a foam surface with eyes closed, when the most marked increase was observed.

For the parameters V_{AP}, V_{ML}, A_{AP}, $A_{ML,}$ LI and TA, which were not normally distributed, the non-parametric Mann Whitney test demonstrated significant differences (P <0.01) between juniors and seniors in all tested conditions (except V_{ML} during stance on a firm surface with eyes open). Between middle-aged and senior categories we found the significant differences in all conditions for V_{AP} (P <0.001), V_{ML} (P <0.05), A_{ML} (P <0.05), LI (P <0.001) and TA (P <0.01). A_{AP} significantly differs (P <0.001) between middle-aged and seniors only with stance on compliant surface with eyes closed. Comparison of the CoP parameters between juniors and middle-aged categories showed significant differences for A_{AP} (P <0.05) under conditions stance on firm surface and on a compliant surface with eyes open and for V_{AP} (P <0.05), LI (P <0.05) and TA (P <0.01) during stance on compliant surface with eyes open. Age-related changes of the CoP amplitude and velocity in AP direction are presented on Fig.3.

For the parameter RMS, which had normal distribution, repeated measures ANOVA comparing three age groups during stance on firm or compliant surfaces and with or without vision gave a significant effect of age (F=25.772, df=2, P<0.001). The effect of surface was also significant (F=80.130, df=1, P<0.001) and there was a linear interaction between surface (firm and compliant) and three age groups (F=6.336, df=2, P=0.003). The analysis revealed significant effect of vision (F=392.856, df=1, P<0.001) and there was also a linear interaction between vision and three age groups (F=5.718, df=2, P=0.005). Furthermore there was a linear interaction between surface versus vision and age groups (F=3.981, df=2, P=0.023). Subsequent Bonferroni-Dunn *post hoc* test demonstrated significant differences (P<0.001) for RMS parameter between juniors and seniors in all tested conditions (Fig.3). Between middle-age and senior categories we found the significant differences (P< 0.05) in all experimental conditions, except condition stance on compliant surface with eyes open. The comparison of junior and middle-aged groups did not revealed significant differences.

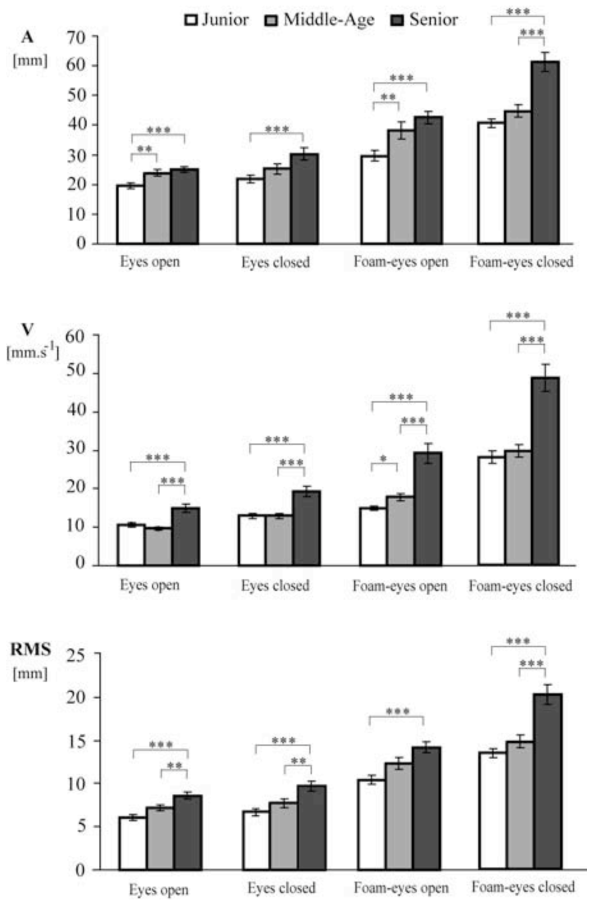

Fig. 3. Comparison of CoP parameters between junior (20-40 years), middle-aged (40-60 years) and senior (60-82 years) age categories in all tested conditions for CoP parameters: amplitude - A and velocity - V in AP direction and root mean square - RMS. The asterisk denotes significant differences * $p<0.05$; ** $p<0.01$; *** $p<0.001$ between the age categories. The values of CoP parameters are expressed as group averages ± SEM.

Analysis of CoP parameters in the complete group of tested subjects revealed significant difference between men and women in some CoP parameters only during stance with eyes closed on firm surface. This was similar only in junior age group where significant difference between men and women during stance with eyes closed was found. For other age groups and tested conditions we have not found the significant gender difference. We have normalized the data with respect to the subject's height but it had minimal effect on gender. Significant gender differences by Student's *t*-Test were found only during stance on firm surface with eyes closed for amplitude (A_{AP}=28.54mm for men, A=23.57mm for women, P=0.040), for velocity in AP direction (V_{AP}=17.55mm.s^{-1} for men, V=14.18mm.s^{-1} for women, *P*=0.048) and for total area of statokinesigram (TA=3202.44mm^2 for men, TA=2346.80mm^2 for women, *P*=0.049).

The values of the CoP parameters in the three examined age categories indicated that the most complex view on postural steadiness during quiet stance is provided by the root mean square (RMS). From the findings of age-related changes in this parameter of CoP values we determined new physiological ranges for all tested conditions in the examined age categories (Fig.4). During stance in all conditions, the new upper ranges were lower in the young and in middle age groups than in the senior age group.

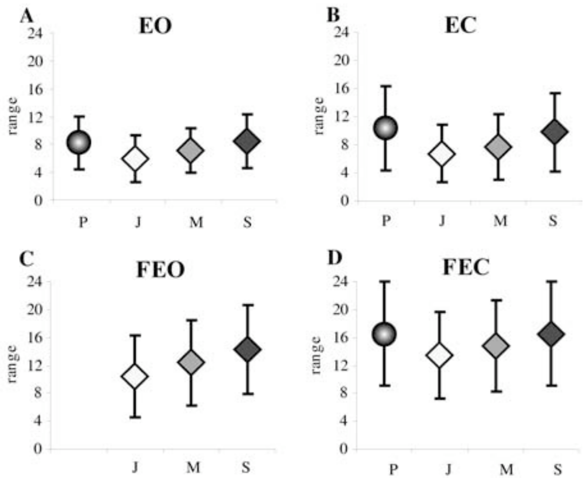

Fig. 4. The new ranges of CoP parameter RMS and previous normative (P) ranges in the tested conditions for the three age categories: J - junior (20-40 years), M - middle-aged (40-60 years) and S - senior (60-82 years); EO-eyes open; EC-eyes closed; FEC-foam support with eyes closed; FEO-foam support with eyes open.

Discussion

The results showed that age-related postural impairment is indicated by significant increase of the CoP parameters values and may be interpreted as slight increase of body sway. The findings are in agreement with previous studies examining balance during quiet stance showing increased body sway in the elderly (Manchester *et al.* 1989, Colledge *et al.* 1994, Prieto *et al.* 1996, Du Pasquier *et al.* 2003, Fujita *et al.* 2005).

It is known that the body sway increases also with deficit of information from one sensory system: visual, vestibular or somatosensory (Lord and Menz 2000). We found that the values of CoP parameters increased significantly in the absence of visual information (with eyes closed) in each age group examined. The increase of the CoP parameters was greater with altered proprioception by standing on a foam rubber surface; further increase occurred when combining the absence of visual information with altered proprioception (Fig. 1, Fig. 3). Our findings indicated significant interaction of vision, support surface and age on slight postural instability documented by increase of RMS parameter. Interesting is that the combination of sensory deficit (visual, somatosensory or both) with advancing age is likely responsible for the postural instability.

When the reliable proprioceptive information from feet and ankles is altered (stance on the foam surface), subjects are compelled to rely more on other sensory (visual and vestibular) and motor systems to maintain stability (Colledge *et al*. 1994, Lord and Menz 2000, Choy *et al.* 2003). Under this condition, subjects swayed more (Lord and Menz 2000) and their vision became more important for maintaining balance (Colledge *et al*. 1994, Choy *et al.* 2003). Our findings showed the increased body sway during stance on foam support with eyes closed as compared with eyes open and this increase was greater in the middle-aged and the greatest in the senior age group (Fig. 3).

When stance on foam is combined with the eyes being closed the substantially greater balance impairment was found in the elderly, as confirmed also by Teasdale *et al*. (1991), Wolfson *et al.* (1992). It is evident that the ability of the older adults to maintain static balance is impaired under conditions of reduced or conflicting sensory information (Manchester *et al*. 1989). Older adults could stand well within their limits of stability when either visual or somatosensory information were reduced or removed, but they began to lose balance when the inputs from both sensory systems were reduced and the main source of sensory information available for keeping balance remained the vestibular input (Woollacott 1993). The stance on foam support with eyes closed is a very relevant test to determine the efficiency of vestibular imbalance, because it not only allows distinguishing the young and elderly, but also helps to discriminate the healthy subjects from the patients with balance disorders caused by vestibular system deficits independent of age (Saling *et al*. 1991).

We found that the noticeable increase of CoP parameters started around 60 years of age. This increase was clearly indicated by root mean square (RMS), amplitude (A) and velocity (V) in AP direction and the impairment of postural stability was better demonstrated during stance on foam surface with eyes closed (Fig 2). Similarly Pyykkö *et al.* (1988) and Hytönen *et al.* (1993) showed that the sway velocity of the oldest examined people (up to 90 years of age) started to increase after the age of 60 years and that this increase was larger during stance on foam surface. According to Du Pasquier *et al.* (2003), the velocity of body sway in AP direction reflects in best way the impairment of ability to maintain stance with aging. Other study suggested that the mean body sway velocity was the best parameter, which showed the most consistent differences between test situations, age ranges and health conditions (Raymakers *et al.* 2005). It was found that velocity of body sway (particularly in the AP-direction) is higher not only in senior subjects but also in seniors with reported imbalance in comparison to age-matched controls (Baloh *et al.* 1995). Prieto *et al.* (1996) also found that the mean body sway velocity revealed age-related differences between young and elderly under conditions of eyes open and eyes closed. The marked age-related changes being found in mean velocity of body sway may indicate that elderly required significantly more postural control to achieve a certain level of steadiness (Prieto *et al*. 1996).

Comparison of the velocity parameters in three age categories pointed out that the velocity of CoP in AP direction is the most sensitive parameter which distinguish not only juniors and seniors but also middle-aged and seniors in all tested conditions. The sensitivity of CoP velocity to age-related balance impairment is documented also by increased significance of this CoP parameter on Fig. 3. Similarly, significant increase in mean velocity of body sway and amplitude in AP direction was found between elderly and young (Perrin *et al.* 1997, Benjuya *et al*. 2004).

Our data indicated the differences between juniors and middle-aged not so clear as between juniors and seniors. This difference was significant only for few analyzed parameters and may be interpreted as minimal change in balance control for juniors and middle-aged groups. This means that the small age-related postural instability is occurred mostly in elderly over 60 years. It is likely that for effective decision to indicate pathological processes in postural control versus age-related postural instability should consider a special increase shape of the CoP parameters values (Fig.2).

The analysis of the RMS parameter by ANOVA and Bonferroni-Dunn *post-hoc* test showed significant differences between juniors and seniors in all tested conditions. Between middle-aged and senior groups the significant differences were found also in all tested condition except stance on compliant surface with eyes open. We determined new physiological ranges (mean ± 2 SD) of the RMS parameter in each tested condition for each age group. The previously published normative ranges of RMS parameter (defined similarly as mean ± 2 SD) were estimated for healthy people disregarding the age of tested subjects (Hlavacka *et al*. 1990). Comparison of the previous and our data (Fig. 4) showed that the published ranges of RMS parameter represent insufficient criteria for distinguish young, middle-aged and elderly people. The new upper ranges of RMS parameter are lower than the previous normative in young and in middle age groups under all conditions. The new upper ranges in the senior group are higher during stance with eyes open and stance on foam with eyes closed. Identification of norms for clinical balance test for most adults may allow identification of deterioration of balance as soon as it occurs in younger people, therefore permitting earlier interventions to target specific impairments (Isles *et al.* 2004).

The problem of gender differences in quiet stance is still open and some authors confirmed it (Wolfson *et al.* 1992) and some authors not (Colledge *et al.* 1994, Bryant *et al.* 2005). We found significant gender differences in some CoP parameters only during stance with eyes closed on a firm surface. After normalization with respect to the subject's height, the significant differences were during stance with eyes closed only for V_{AP}, A_{AP}, and TA. As a whole we think that our study has not enough data to support gender difference in balance control during quiet stance.

Our findings confirmed significant decline in balance due to aging followed by increase of CoP parameter values and identify the most sensitive CoP parameters (mainly RMS) able to demonstrate balance changes. Impaired postural control in the elderly may reflect general age-related deficits in the postural control system as well as possibly specific pathologies which may be unique to each individual and are often subclinical (Horak *et al*. 1989). According to Fujita *et al*. (2005) detailed analysis of sway parameters appears to be important to help in the understanding of age-associated body sway and its undesirable complications.

We concluded that the most complex view on balance control during quiet stance in each examined age category was provided by RMS parameter. The new normative ranges for healthy subjects, especially for root mean square (RMS) in stance on foam with eyes closed will be useful to distinguish better between small postural instability due to aging and pathological processes of postural control. Identification of age-induced balance instability during quiet stance may thereafter lead to improve assessment and rehabilitation of individuals with balance disorders to increase the quality of life of seniors.

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