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The contribution of postural balance analysis in older adult fallers: a narrative review

Abstract:

Objective. Falls are a serious health problem for older adults. Several studies have identified the decline of postural balance as one of the main risk factors for falls. Contrary to what may be believed, the capability of force platform measurements to predict falls remains uncertain. The focus of this narrative review is the identification of postural characteristics of older adults at risk of falling using both static and dynamic postural balance assessments. **Methods.** The literature analysis was conducted on Medline/PubMed. The search ended in May 2015. **Results.** Centre of pressure (CoP) path length, CoP velocity and sway in medial lateral and anterior-posterior are the variables that distinguish older adult fallers from non-fallers. **Discussion.** Recommendations to medical personnel on how to provide efficient balance training for older adults are offered, discussing the relevance and limitations of postural stability on static and dynamic board in falling risk prevention.

Keywords

centre of pressure, dynamic posturography, static posturography, falls, older adults.

INTRODUCTION

Falls are a serious health problem for older adults (Tinetti 1994); in fact decreasing balance with age is one of the major risk factors for falling (Piirtola & Era 2006). A great number of falls in older adults are caused by wrong and inadequate (ipometric: reduced/small sway responses and ipermetric: excessive/large sway responses) responses to the perturbations in the sagittal and frontal plane (Maki et al 1994); moreover, it is well documented that the quantification of the centre of pressure (CoP) movements during lateral perturbation could predict subsequent falls (Piirtola & Era 2006). Older adults are unaware that their performance impairments, such as their physical activity (muscular strength and resistance) and sensorial reflex capacity (increase of reaction time and sensorial deficits), determine a general decline of their motor system and autonomy (Brach & VanSwearingen 2002; Maki et al 1994). The difficulty in recognizing these physical deficits limits seniors in an adequate postural reaction to protect themselves by the impact of falling.

Objective. This review intends to offer an overview of experimental works providing a basis for the comprehension and prevention of falls and fall-related injuries in older adults. It has two goals: i) to describe the methods and equipment commonly used in measuring static and dynamic postural balance and to report their capacities to distinguish between fallers and non-fallers, ii) to detail some specific characteristics of older fallers, such as muscular strength, frailty, sensorimotor aspects, usually related in literature, to postural balance field.

METHODS

Design. The manuscript's starting point is a joint biomechanical, physiological and functional approach, and introduces some basic concepts which constitute a background for the topic of balance measurement (static and dynamic balance assessments) in older adults. Then the relevance and limitations of postural stability on static and dynamic boards in prevention of falling risk in older adults are discussed. Finally, distinguishing characteristics of older "fallers" and "non-fallers" are assessed.

Setting. The literature analysis was conducted on Medline/PubMed. The search ended in March 2015 and is limited to works published between 1970 and 2015. The language was limited to English. The following primary search terms were entered: static balance, dynamic balance, static board, dynamic board, static platform, moving platform, older adults, aging, risk of falling, proprioception, postural control, postural coordination, postural strategy, fallers, non-fallers, dynamic posture training, fall prediction index, clinical measures of dynamic balance, clinical measures of static balance and reliability.

Articles were collected on the basis of the following criteria, studies that evaluate risk of falling and used balance platform assessment. Only studies conducted on community-dwelling healthy male and female subjects aged 65 and over were considered. Studies of institutionalized subjects were excluded. Participants with medical factors affecting balance were excluded. The scientific quality of selected papers relied on Medline and PubMed criteria.

Among the eligible studies, the papers that did not treat or report parameters in static or dynamic balance were excluded. Published abstracts, conference presentations, dissertation materials were not considered in this review.

Background

Balance measurements

Posturography, which literally refers to the description of posture, is an approach to the assessment of postural balance utilizing force platforms providing a number of parameters reflecting postural stability. Computerized balance platforms offer objective measurements of sway under different conditions in clinical settings (Grabiner et al 1993; Jarnlo & Thorngren 1993).

Essentially there are two types of clinical posturography static platform and dynamic platform posturography (Di Fabio 1995). Data thus obtained need to be generalized to provide reproducible results performing the assessment in a standardized way on reliable equipment. Few studies (Lafond et al 2004) evaluate the reliability of CoP measures in older adults during quiet standing. Moreover, results on repeatability are often incomplete or unsatisfactory, and mostly concern test-retest, inter-tester reliability (Ageberg et al 1998; Mattacola et al 1995) only of the centre of pressure minus centre of mass (CoP-CoM) measure and of the time of CoP maintenance (Corriveau et al 2000; King & Zatsiorsky 2002; Lafond et al 2004).

Recently some authors investigated postural balance in older adults using classical stabilometric measures extracted from CoP analysis in association to dynamic measures that the quantities describing the temporal structure of CoP trajectories, underlying their importance as postural signatures in this kind of population (Tallon et al 2013).

Static balance assessment

Static platform posturography involves stance or tandem stance on a fixed platform with eyes open or closed (Black & Wall 1981; Norre & Forrez 1986). This procedure is based on the Romberg tests and the outcome is quantified with respect to changes in CoP sway area, path length, or velocity (Di Fabio 1995).

In the tradition of Romberg (1853), a subject has to stay in upright position on a footboard in different stance positions (double limb, tandem or single limb) and visual condition (eyes open, eyes closed). A reduced postural sway about the central equilibrium point shows less movement, hence, greater stability control (relative to her/his age-matched peers). Optimal postural control in quiet standing therefore, is characterized by small CoP oscillations in amplitude, relatively unconstrained and irregular. Usually during balance tests the time that subjects are able to maintain a particular equilibrium position is recorded (Bogle Thorbahn & Newton 1996; Graybel & Fregly 1966) as further information for classification.

Control of posture is connected to attention and to the instructional set, therefore these parameters should be considered in testing protocols of postural control (Nishiwaki et al 2000). These authors evaluated the influence of two different instructional sets (one with the request to relax the body and the other with the request to minimize body sways). Results indicated that rigorous and clear instructions should be recommended when a stabilometric test is performed in an investigation.

In 2002 some authors (Chiari et al 2002) showed the importance of biomechanical factors on anterior-posterior and medium-lateral stabilometric variables. Particular attention was given to weight, height, base of support area, feet-opening angle and maximum foot width during between-subject comparisons. In 2004 (Rocchi et al 2004) to promote standardization in quantitative posturography, the same authors suggested that if no normalization is undertaken, it is essential to constrain the foot position in such a way as to reduce inter-subject variability of base of support measurements. Furthermore, they underlined the need to align properly the reference frame of the subject with the reference frame of the platform.

Corriveau et al. (2000) found that the variable CoP-CoM is a reliable measurement of postural stability in healthy older adults. In 2001 (Corriveau et al 2001) the same authors estimated the test-retest and inter-rater reliability of that variable (CoP-CoM) in older subjects. This was obtained using the equivalence of the test-retest and inter-rater coefficients, concluding that the measurement of the CoP-CoM is mainly related to individual variability of these measures over two separate occasions within seven days. The mean of four trials was found sufficient to assess that CoP-CoM variable potentially can be used to track clinical change in older adults.

With ageing CoP variables showed better relative repeatability (intraclass correlation coefficient) and comparable absolute reliability (standard error of the mean) except for sway area and mean velocity. These results could be useful for the interpretation of CoP based findings (Lin et al 2008). Jancovà & Tosnerovà (2007) claimed that the double narrow stance tests (heels and toes touching) with eyes open and with eyes closed are comparable especially with adults aged 65 and older.

In 2014, Jørgensen found that there is a systematic time-of-day influence on static postural balance in older adults using the Nintendo Wii (Jorgensen 2014). In particular findings have shown an increase of some postural variables (total COP sway length, confidence ellipse area, total sway area and velocity-moment) in the afternoon compared to mid-day and the morning trials.

Dynamic balance assessment

Dynamic force platforms measure the displacement of a subject's CoP under dynamic conditions usually using four force transducers and a displacement device for moving the support surface of the platform. Using a movable support surface it is possible to assess the contribution of the visual system, the somatosensory system and the vestibular system during individual response to balance perturbations. Dynamic platform posturography also uses Romberg's tests, but test conditions in which the platform and visual environment are moved to reduce the subject's ability to use visual and somatosensory information for balance were specified (Black et al 1983; Nashner & Peters 1990). Moreover, dynamic platform posturography also adopted a movable support surface to test the subject's response to balance perturbations. Some platforms in fact, stress the vestibular system, measure the quality of the maintenance of subjects' balance while the walls of the booth move (Cavanaugh et al 2005). Experimentally induced balance perturbations are in one or multiple directions (vertical, horizontal displacements or a combination of the two modalities) (Henry et al 1998) and also the intensity of the perturbations can vary greatly. Some authors aimed to investigate stimulus anticipation and postural control mechanisms of feed-forward using oscillatory and slow movements, whereas other investigators, (Tsai et al 2014) interested in quick postural reactions, adopted rapid, continuous and sudden movements of the balance supports. In general older adults have shown asymmetric and weaker muscle power and torque resistance compared to young subjects, and this affects their ability to restore postural control. Moreover, to produce agonist torque in an upright stance older adults require more muscle activity than young people, causing a premature fatigue process and increasing the risk of falling.

The sensitivity of posturography in therapeutic interventions varies greatly among authors and insufficient methodological details are reported in papers to reach standardized protocols (Asai et al 1993; Black & Wall 1981; Black et al 1983; Hamid et al 1991; Nashner & Peters 1990; Voorhees 1989).

Predictive models of postural control system output involve both linear and nonlinear dynamics frameworks, as described in a review article (Cavanaugh et al 2005). Linear models are based on individual system components and study the magnitude of output signal variability. Nonlinear models are based on the time evolutionary properties of an output signal to highlight inferences about interactions within the underlying control system. Moreover, nonlinear dynamics have the capability of being adaptable and flexible in an unpredictable and ever-changing environment (Buzzi et al 2003).

Contradictory results were found in studies (Brauer et al 2002; Hsiao-Wecksler et al 2007; Luchies et al 1994; Mcllroy et al 1996; Rogers et al 2001; Thelen et al 1997; Woijcic et al 1999) investigating age-related impairments in rapid "change-in-support" (stepping or grasping) balance-recovery reactions using various perturbation methods. Mansfield and Maki (2009) suggested that the variances could be provoked by several mechanical and sensory stimuli supplied by the different perturbation methods, but could also be caused by other confounding factors (e.g., differences in perturbation predictability).

Static balance and falls

Since, as just described, there is a lack of consensus about the ability of force platform measures to predict falls, the present narrative review is also aiming at describing age-related changes in postural control in relation to falls, and the balance assessment ability in identifying fallers among older adults.

Consequently “a recalled fall was the most important predictor for future falls” (Gerdhem et al 2005). However, other data could predict subsequent falls. Among the different parameters derived from signals recorded with force platforms (Baloh et al 1994), indicators of lateral balance such as mean speed of the mediolateral (ML) movement of the centre of pressure (CoP) during normal standing with and without visual inputs, mean amplitude of the ML movement of the CoP with the eyes open and closed, and the rootmean-square value of the ML displacement of CoP are the best indicators for detecting differences between future fallers and older adults with no risk of future falls.

Increased postural sway in older adults is well documented (Hasselkus & Shambes 1975) and greater amounts of postural sway are correlated to increased risk of falling (Fernie et al 1982). Mean Sway Area in the medial-lateral, anterior-posterior directions, and Mean Sway Velocity were found to be higher in fallers (Fernie et al 1982; Maki et al 1994; Melzer et al 2004).

The postural control system adopts open-loop control mechanisms over the short-term time interval and the closed-loop control mechanisms over the long-term to maintain quiet stance. An open-loop control system is characterized by the absence of sensory feedback; on the contrary, a closed-loop control system operates with sensory feedback, such as vestibular, visual and somatosensory systems (Laughton et al 2003).

Benjuya et al (2004) compared CoP-based measures during wide base stance (feet apart) and narrow base stance (feet placed together) with both eyes open and eyes closed. They found significant differences between fallers and non-fallers in most CoP based measurements in narrow stance. Fallers showed significantly higher CoP path length, CoP velocity and the movements of the CoP in the ML direction during the eyes open test, compared to non-fallers. With eyes closed, fallers had a significantly higher CoP path length, CoP velocity, elliptical area and ML sway. Multiple regression analysis revealed that people who showed a higher ML sway had three times greater risk of falling. Lord et al (1994) and Stel et al (2003) also found that fallers had an increased ML sway in a near tandem stability test with eyes open and closed. In the same way, Maki et al (1994) concluded that lateral spontaneous sway was the best predictor of future falls. Moreover, the latter found that older adults also showed a loss of cutaneous sensation, which appears to have a fundamental role in postural control. In fact some authors demonstrated that fallers had lower proprioception and more dependence on visual inputs. For example, Melzer et al (2004) reported that, using foamed surfaces, somatosensory input from feet of older adult fallers appears to be less important than vision in maintaining balance in narrow stance.

Narrow stance on foam provoked a reduction in somatosensory input and the non-fallers showed a 5% increase in CoP path length compared to the fallers group. So fallers seem to be less influenced by a reduction in somatosensory input from the feet. CoP path length with eyes closed compared to eyes open, increased equally (20%) in the two groups. Therefore, fallers used less somatosensory information than non-fallers and had a greater dependence on visual information. Moreover, impaired plantar cutaneous sensation in older people would delay compensatory step or grasp reaction times when a fall occurs, due to inability to detect the CoP movement under the feet.

Dynamic balance and falls

During a perturbation in anterior-posterior (AP) direction of an unstable board feet act as pistons conducting the pelvis in the same direction of the inclination while the trunk is moved in the opposite direction and ankle flexion starts before knee flexion (Fujiwara et al 2007). When a subject is on a movable platform, the postural adjustments (95-120 ms of latencies) are activated to restore the centre of gravity; these muscle responses can be measured, for instance with surface electromyography. Thanks to this technique it was shown that older adults had more antagonist muscle activation than young adults adopting “hip strategy” to restore postural balance (Manchester et al 1989).

In older people roll directions of the trunk were in the same direction of the board movements (Allum et al 2002) with a bigger latency of the postural responses in the distal muscles of the lower limbs (Tibialis anterior and Gastrocnemius). In the results on voluntary sway older adults were found to have slower, less reliable postural reflexes that were less responsive to the demands of voluntary movement. The poorer coordination of postural reflexes with voluntary movement suggests that with advancing age there are problems with the hierarchical organization of movement (Stelmach et al 1989). Muscular activation starts from proximal muscles (hip/trunk), to distal muscles (leg/thigh) in contrast to adults (<60 y.o.). Moreover, it was shown that during aging isometric and concentric muscle strength is reduced due to atrophy, deterioration of mechanical properties and motor unit loss (Hortobagyi et al 1995). The most important characteristic of the ankle muscle strength in seniors is the dorsiflexion weakness, which is also liable to postural instability in this population (Larsson et al 1979); these are the reasons for the overuse of visual inputs and deficit in somatosensory information observed in this age group (Granacher et al, 2011).

In fact older adults loose stability and need assistance during the tests when the vestibular channel is the only one used. Findings from literature show that as long as visual and vestibular inputs are available, both young and older adults can shift easily from the use of one sensory input to another. However, when only one sensory input (the vestibular system) is available, the sway of the older adult is impaired sufficiently to cause loss of balance in many trials (Woollacott & Shumway-Cook 1990).

Wolfson et al (1994) found gender differences in healthy older adults for balance responses to platform perturbations. They demonstrated that women lost their balance more frequently than men during toes-up-and-down rotations and during repeated toes-up rotations. Women also developed smaller angular momentum than men in response to forward platform rotations. The use of a dynamic platform allowed the understanding of an important characteristic of older women - their greater frequency of falling when in stressed balance conditions.

In bipedal stance, medio-lateral swaying reflects the ability to distribute the body weight evenly between the two lower limbs. The muscles involved are the hip abductors/adductors and the ankle pronators/supinators. Antero-posterior sway, in contrast, reflects variations in the activity of the ankle flexors (Day et al 1993).

To assess age-related changes of the sensorimotor mechanisms underlying dynamic equilibrium, Nardone et al (2000) tested body segment coordination during equilibrium on a dynamic platform. From the age of 20 to 70 years such latencies increased by about 20 msec (Nardone et al 1994), possibly because of the age-related reduction in nerve fibre conduction velocity. The ability of older subjects to hold head stability during eyes open performance discounts the possibility that the less stable behaviour without visual inputs is caused by strength decline, or by reduced joint motion range or by sedentary condition. Increasing age provoked a decrease of postural performances during eyes closed condition, but did not appear to be a critical factor for the stability on dynamic platforms with translation frequency up to 0.6 Hz.

Potential factors that can change training protocols on an unstable board are fear, fatigue, pain and motivation. These factors can be balanced by providing frequent rest periods, verbal encouragements and comfortable safety precautions in the experimental setup (Gschwind et al 2013).

In his review Emery (2003) claimed that reliability and validity of dynamic standing balance measurement tools still need to be assessed for proper clinical settings. Reference values are actually provided only by producers; trials on large populations are needed to obtain normality indices.

Distinguishing characteristics of older “fallers” and “non-fallers”

In 2002 Lajoie et al compared older adult fallers and non-fallers during different tests such as postural sway, reaction time, the Berg Balance Scale and the Activities-specific Balance Confidence Scale, in order to determine reliable predictors. Findings highlighted that reaction time was the best predictor of fall status. Other authors found that the CoP displacement correlates negatively with the maximal isometric torque of ankle muscles, (Billot et al 2010) and recently the decrease in ankle muscle strength was found to be one of the marker factors for impaired postural stability in older adults. A torque value of 3.1 $N \cdot m \cdot kg^{-1}$ was found to distinguish between fallers and non-fallers, suggesting that measuring ankle torque could be used in routine clinical practice to identify potential fallers (Cattagni et al 2014). Thus the loss of lateral postural control in fallers could be explained by an asymmetric muscle strength loss in their lower limbs. Good lateral postural control is essential for a protective role in response to destabilizing events (Rogers et al 2001).

When strategies are inadequate to maintain stance a stepping response is often used. Medell and Alexander (2000) demonstrated substantial declines in the ability of older adults to step maximally and rapidly. They supported the hypothesis that one leg stance ability might be differentiate between falls and fall-related injuries risk. Thelen et al (1997) found that there are substantial age-related declines in the ability to regain balance by taking a rapid step among healthy adults when the time available for recovery is short.

A number of experiments adopted different balance perturbation techniques (Pijnappels et al 2005; Van Dieen et al 2005). Hsiao-Wecksler (2007) reviewed experimental studies using the techniques of forward fall (trip) or backward fall (slip) to examine how recovery behaviour is affected by the adopted experimental protocol, and by age, gender, direction of release, instructions and constraints on recovery strategies. Strong associations between recovery ability and biomechanical parameters such as step length, step timing and joint torques highlighted the importance of neuromuscular capacities in relation to lower extremity flexibility, reaction time and muscular strength. Therefore, the maintenance or enhancement of these abilities should be considered in the development of exercise-based intervention programmes for fall prevention in older adults.

In impending fall situations a stepping response is often used when strategies to maintain stance are weak. Older adults' ability to recover their balance with a single backward step depends primarily on the configuration of the body (in particular the ratio between stepping angle and body lean angle) at step contact (Hsiao & Robinovitch 2001). This aspect should be considered in balance assessment and training (Hsiao-Wecksler 2008). Medell and Alexander (2000) found substantial decreases in the ability of both unimpaired and balance-impaired older adults to step maximally and to step rapidly. Stepping performance is closely related to other measures of balance and fall risk. Greater postural sway in both anterior-posterior and medio-lateral directions and trends of greater muscle activity were found in those older adults who had lower scores on clinical measures of balance (Laughton et al 2003).

The evaluation of the handgrip strength, as well as the leg extension strength, is capable of predicting recurrent falls using an easy survey and giving high reliability (Greig 1994; Merlini et al 2002), and is more effective if considered in relations to a number of fall predictors. Handgrip results significantly distinguish recurrent fallers, occasional fallers and non-fallers (Chu 2005; Rosengren 2012), since according to Pijnappels et al (2008) handgrip strength is significantly correlated with lower limb muscular strength.

Recently obesity was also identified as a factor affecting fall risk (Vincent et al 2012). Obese older adults are more likely to fall than others, but the effect of weight on the risk of falling did not appear to be linear (Pataky et al 2014). A longitudinal study by Himes and Reynolds (2012) indicates that obese older adults are more likely to fall than others;

moreover, obesity in Class 1 body mass index (BMI) 30.0-34.9 kg/m^2, and Class 2 BMI 35.0-39.9 kg/m^2 was related to greater likelihood of more disability after a fall, whereas in obesity Class 3 BMI $\geq$ 40.0 kg/m^2 a protective effect was found, these people are significantly less likely to be injured in a fall than normal-weight individuals.

The above mentioned parameters (e.g., muscle strength in lower limbs, handgrip strength and body weight) were frequently included in the ageing-related literature as operational definitions of frailty (Fried 2001; Gobbens et al 2010; Studenski et al 2004). In fact, researchers reported a significant difference in terms of frailty between fallers and non-fallers among older adults. A study of Samper-Ternent et al (2012) showed the lowest rates of falls for robust (incident rate ratio, IRR 1.9), followed by pre-frail (IRR 2.6), and frail (IRR 3.2) older adults. Similarly, Ensrud et al (2007) found that pre-frail and frail women had increased age-adjusted odds of recurrent falls in comparison to robust women. Frailty and recurrent falls showed a stronger association among women older than 80 years than younger older women (69-79 years old). Moreover, Kang et al (2009), studying quantitative posturography in frail and robust older adults, found measures of CoP path length and mean power frequency statistically higher in frail subjects. Identification of pathways related to frailty and falls, and their association with the previously mentioned biomechanics, physiological and anthropometric parameters, can provide meaningful information for the early identification of older adults at risk of becoming fallers.

DISCUSSION

The fact that balance disorders can arise from a multifactorial range of causes explains the interest from a wide variety of therapists such as neurologists, otoneurologists, physical and occupational therapists. Force platforms were widely used as a tool to assess balance; however, objective and validated data on these matters is urgently needed. This review has shown that balance evaluations are very different, both in protocols and in measurement methods, and that direct comparisons among studies and data interpretation are extremely limited. Many experimental protocols indicated that increased postural sway in older adults is well documented and research findings highlighted a correlation between postural sway and increased risk of falling not only on a static board (Baloh et al 1994; Benjuya et al 2004; Billot et al 2010; Fernie et al 1982; Hasselkus & Shambes 1975; Kang et al 2009; Lajoie et al 2002; Lord et al 1994; Maki et al 1994; Melzer et al 2004; Stel et al 2003), but also on an unstable board (Nardone et al 1994; Nardone et al 2000; Woollacott & Shumway-Cook 1990; Wolfson et al 1994; Rogers et al 2001). All these authors are in agreement that considering the measurement of balance is important for fall risk prediction and the evaluation of effectiveness of balance-training programmes in preventing falls. Precisely analyzing findings of experiments conducted with different trials such as Romberg test and one legged stance test, it is possible to conclude that older adult fallers showed significantly higher CoP path length, CoP velocity and sway in medial lateral and anterior-posterior direction in eyes open conditions (Marigold & Janice 2006; Melzer et al 2004; Prieto et al 2002). Moreover, in eyes closed conditions, a higher elliptical area was observed in fallers, in contrast to seniors without a history of falls. Fallers also demonstrated a decrease in proprioception, visual acuity, quadriceps strength and cutaneous sensation (Larsson et al 1979; Maki et al 1994; Melzer et al 2004). These older adults were thus less accustomed to use somatosensory information and showed a greater dependence on visual inputs (Granacher et al 2011).

Medial lateral sway in both the conditions (eyes open and closed) was found to be a distinguishing variable between older “fallers” and “non-fallers” in both static and dynamic narrow stance condition (Melzer et al 2004). No works showed balance training on stabilometric and dynamic boards as a tool to reduce falls and fall-related injuries in older adults. Findings indicated that neuromuscular capacities related to lower extremity flexibility, reaction time and strength were all pivotal for balance recovery. Some works (Debra 2008; Lee et al 2013) focused on physical training programmes on balance recovery to prevent falls but no papers proposed protocol training on those dynamic platforms moving in both transverse and sagittal planes. Exercise programmes with a strong balance component have been found to be most effective in preventing falls (Campbell et al 1999; Lord et al 2003; Province et al 1995). To date few studies have used perturbations to train stepping reaction. Perturbation-based training of Change In Support (CIS) reactions, involving very rapid stepping or grasping movements of the limbs to restore balance, were adopted in scientific works. Authors (Mansfield et al 2010; Rogers et al 2003; Shimada et al 2004;) showed how to improve volitional reaction time in older adults. They did not assess the effects of the training on compensatory stepping and whether the effective benefits reduce fall risk in daily life.

In their review Maki et al (2008) described four new interventions aimed at reducing fall risk in older adults, by promoting more effective CIS reactions, using unpredictable support-surface dynamic perturbations in all four directions. They concluded that their intervention approach has the potential to counteract lateral instability. This aspect gains more importance because some authors, analyzing the non-linear behaviours of viscoelastic loading at the joints, found that the increased ML viscosity in older adults was the only predictor of falls (Kuczynski & Ostrowska 2006).

In conclusion, the variables and techniques adopted to quantify balance were different in each research (Chaudhry et al 2011). Insufficient evidence exists from well-designed, prospective, randomized, controlled trials to draw definitive conclusions about the impact of dynamic board testing on health outcomes in large populations (Tsai et al 2014). The diagnostic utility of such a tool has not been demonstrated and any qualitative data provided by dynamic equilibrium board testing does not establish definitive findings. No studies are available to evaluate the effectiveness of dynamic equilibrium board testing with respect to standard testing methods; no findings showing that the use of this instrument would improve treatment decision-making are available. No studies have managed the balance training using protocols on a dynamic board with the subject able to move the mobile platform very easily in flex-extension and anterior-posterior positions. This freedom of movements in the four axes produces unexpected changes of equilibrium, which are useful to restore quickness and agility of lower limbs and trunk muscles.

Hence further research analyzing CoP variables needs to be undertaken and further studies are needed to assess the role of unstable postural board testing in the management of subjects with the risk of falling. Finally, since insufficient evidence exists that any screening instrument is adequate for predicting falls (Gates et al 2008), this review provides important information in order to encourage further development of novel interventions based on an integration of stabilometric measurements with functional tests in order to detect potential fallers at an early stage and assess the predictive role of a number of parameters.

REFERENCES

Ageberg E, Zatterstrom R, Moritz U 1998. Stabilometry and one-leg hop test have high test-retest reliability. Scandinavian journal of medicine & science in sports, 8(4), 198-202.

Allum JH, Carpenter MG, Honegger F, Adkin AL, Bloem, BR 2002. Age-dependent variations in the directional sensitivity of balance corrections and compensatory arm movements in man. The Journal of Phisiology, 542(Pt 2), 643-663.

Asai M, Watanabe Y, Ohashi N, & Mizukoshi K 1993. Evaluation of vestibular function by dynamic posturography and other equilibrium examinations. Acta Oto-laryngologica Supplementum, 504, 120-124.

Baloh RW, Fife TD, Zwerling L, Socotch T, Jacobson K, Bell T, et al 1994. Comparison of static and dynamic posturography in young and older normal people. Journal of the American Geriatrics Society, 42(4), 405-412.

Benjuya N, Melzer I, Kaplanski J 2004. Aging-induced shifts from a reliance on sensory input to muscle cocontraction during balanced standing. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 59(2), 166-171.

Billot M, Simoneau EM, Van Hoecke J, Martin A 2010. Age-related relative increases in electromyography activity and torque according to the maximal capacity during upright standing. European Journal of Applied Physiology, 109(4), 669-680. doi: 10.1007/s00421-010-1397-7

Black FO, Wall, C 1981. Comparison of vestibulo-ocular and vestibulospinal screening tests. Otolaryngology -- Head and Neck Surgery, 89(5), 811-817.

Black FO, Wall C, Nashner LM 1983. Effects of visual and support surface orientation references upon postural control in vestibular deficient subjects. Acta Oto-laryngologica Supplementum, 95(3-4), 199-201.

Bogle Thorbahn LD, Newton RA 1996. Use of the Berg Balance Test to predict falls in elderly persons. Physical Therapy,76(6), 576-583; discussion 584-575.

Brach JS, VanSwearingen JM 2002. Physical impairment and disability: relationship to performance of activities of daily living in community-dwelling older men. Physical therapy, 82(8), 752-761.

Brauer SG, Wollacott M, Shumway-Cook A 2002. The influence of a concurrent task on the compensatory stepping response to a perturbation in balance-impaired healthy elders. Gait and Posture, 15, 83–93.

Buzzi UH, Stergiou N, Kurz MJ, Hageman PA, Heidel J 2003. Nonlinear dynamics indicates aging affects variability during gait. Clinical Biomechanics (Bristol, Avon), 18(5), 435-443.

Campbell, A. J., Robertson, M. C., Gardner, M. M., Norton, R. N., & Buchner, D. M. (1999). Falls prevention over 2 years: a randomized controlled trial in women 80 years and older. Age and Ageing, 28(6), 513-518.

Cattagni T, Scaglioni G, Laroche D, Van Hoecke J, Gremeaux V, Martin A 2014. Ankle muscle strength discriminates fallers from non-fallers. Frontiers in Aging Neuroscience, 6, 336. doi: 10.3389/fnagi.2014.00336

Cavanaugh JT, Guskiewicz KM, Giuliani C, Marshall S, Mercer V, Stergiou N 2005. Detecting altered postural control after cerebral concussion in athletes with normal postural stability. Britisch Journal of Sport Medicine, 39(11), 805-811. doi: 39/11/805 10.1136/bjsm.2004.015909

Cavanaugh JT, Guskiewicz KM, Stergiou N 2005. A nonlinear dynamic approach for evaluating postural control: new directions for the management of sport-related cerebral concussion. Sport Medicine (Auckland, N.Z.), 35(11), 935-950.

Chaudhry H, Bukiet B, Ji Z, Findley T 2011. Measurement of balance in computer posturography: Comparison of methods--A brief review. Journal of Bodywork and Movement Therapies, 15(1), 82-91. doi: 10.1016/j.jbmt.2008.03.003

Chiari L, Cappello A, Lenzi D, Della Croce U 2000. An improved technique for the extraction of stochastic parameters from stabilograms. Gait & Posture, 12(3), 225-234.

Chiari L, Rocchi L, Cappello A 2002. Stabilometric parameters are affected by anthropometry and foot placement. Clinical Biomechanics (Bristol, Avon), 17(9-10), 666-677. doi: S0268003302001079

Chu LW, Chi I, Chiu AY 2005. Incidence and predictors of falls in the chinese elderly. Annals of the Academy of Medicine, Singapore, 34(1), 60-72.

Corriveau H, Hebert R, Prince F, Raiche M 2000. Intrasession reliability of the "center of pressure minus center of mass" variable of postural control in the healthy elderly. Human Movement Science, 81(1), 45-48.

Corriveau H, Hebert R, Prince F, Raiche M 2001. Postural control in the elderly: an analysis of test-retest and interrater reliability of the COP-COM variable. Archives of Physical Medicine and Rehabilitation, 82(1), 80-85.

Cumming RG, Klineberg RJ 1994. Fall frequency and characteristics and the risk of hip fractures. Journal of the American Geriatric Society, 42(7), 774-778.

Day BL, Steiger MJ, Thompson PD, Marsden CD 1993. Effect of vision and stance width on human body motion when standing: implications for afferent control of lateral sway. J Physiol 469, 479-99.

Debra JR 2008. Preventing falls among older adults: No “one size suits all” intervention strategy. Journal of Rehabilitation Research and Development, 45(8), 1153–1166.

Di Fabio RP 1995. Sensitivity and specificity of platform posturography for identifying patients with vestibular dysfunction. Journal of the Rehabilitation research and Desorders, 75(4), 290-305.

Emery CA 2003. Risk factors for injury in child and adolescent sport: a systematic review of the literature. Clinical Journal of Sport Medicine, 13(4), 256-268.

Ensrud KE, Ewing SK, Taylor BC, Fink HA, Stone KL, Cauley JA 2007. Frailty and risk of falls, fracture, and mortality in older women: the study of osteoporotic fractures. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 62(7), 744-751.

Era P, Heikkinen E 1985. Postural sway during standing and unexpected disturbance of balance in random samples of men of different ages. Journal of Gerontology, 40(3), 287-295.

Fernie GR, Gryfe CI, Holliday PJ, Llewellyn A 1982. The relationship of postural sway in standing to the incidence of falls in geriatric subjects. Age and Ageing, 11(1), 11-16.

Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J 2001. Frailty in older adults: evidence for a phenotype. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 56(3), M146-156.

Fujiwara K, Kiyota T, Maeda K, Horak FB 2007. Postural control adaptability to floor oscillation in the elderly. Journal of Physiological Anthropology, 26(4), 485-493.

Gschwind YJ, Kressig RW, Lacroix A, Muehlbauer T, Pfenninger B and Granacher U 2013. A best practice fall prevention exercise program to improve balance, strength / power, and psychosocial health in older adults: study protocol for a randomized controlled trial. BMC Geriatrics, 13, 105.

Gates S, Smith LA, Fisher JD, Lamb SE 2008. Systematic review of accuracy of screening instruments for predicting fall risk among independently living older adults. Journal of Rehabilitation Research and Development, 45(8), 1105-1116.

Gerdhem P, Ringsberg K, Akesson K 2005. Clinical history and biologic age predicted falls better than objective functional tests. Journal for Clinical Epidemiology, 58(3), 226-232.

Gobbens RJ, van Assen MA, Luijkx KG, Wijnen-Sponselee MT, Schols JM 2010. The Tilburg Frailty Indicator: psychometric properties. Journal of the American Medical Directors Association, 11(5), 344-355. doi: 10.1016/j.jamda.2009.11.003

Grabiner MD, Lundin TM, Feuerbach JW 1993. Converting Chattecx Balance System vertical reaction force measurements to center of pressure excursion measurements. Physical Therapy, 73(5), 316-319.

Granacher U, Muehlbauer T, Gollhofer A, Kressig RW, Zahner L 2011. An Intergenerational Approach in the Promotion of Balance and Strength for Fall Prevention – A Mini-Review. Gerontology, 57, 304–315.

Graybel A, Fregly A 1966. An ataxia test battery. Acta Oto-laryngologica, (61), 292-321.

Greig CA, Young A, Skelton DA, Pippet E, Butler FM, Mahmud SM 1994. Exercise studies with elderly volunteers. Age and Ageing, 23(3), 185-189.

Guideline for the prevention of falls in older persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. (2001). Journal of the American Geriatrics Society, 49(5), 664-672.

Hamid MA, Hughes GB, Kinney SE 1991. Specificity and sensitivity of dynamic posturography. A retrospective analysis. Acta Oto-laryngologica Supplementum, 481, 596-600.

Hasselkus BR, Shambes GM 1975. Aging and postural sway in women. Journal of Gerontology, 30(6), 661-667.

Henry SM, Fung J, Horak FB 1998. EMG responses to maintain stance during multidirectional surface translations. Journal of Neurophysiology, 80(4), 1939-1950.

Himes CL, Reynolds SL 2012. Effect of obesity on falls, injury, and disability. Journal of the American Geriatrics Society, 60(1), 124-129. doi: 10.1111/j.1532-5415.2011.03767.x

Hortobagyi T, Zheng D, Weidner M, Lambert N, Westbrook S, Koumard J 1995. The influence of ageing on muscle strength and muscle fiber characteristics with special reference to eccentric strength. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 50(6), B399-406.

Hsiao-Wecksler ET 2008. Biomechanical and age-related differences in balance recovery using the tether-release method. Journal of Electromyography and Kinesiology,18(2), 179-187.

Hsiao-Wecksler ET, Robinovitch SN 2007. The effect of step length on young and elderly women's ability to recover balance. Clinical Biomechanics (Bristol, Avon), 22(5), 574-580.

Hsiao-Wecksler ET, Robinovitch SN 2001. Elderly subjects' ability to recover balance with a single backward step associates with body configuration at step contact. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 56(1), M42-47.

Jancovà J, Tosnerovà V 2007. Use of stabilometric platform and evaluation of methods for further measurements a pilot study. Acta Medica (Hradec Kralove), 50(2), 139-143.

Jarnlo GB, Thorngren KG 1993. Background factors to hip fractures. Clinical Orthopaedics and Related Research**,** (287), 41-49.

Jorgensen MG 2014. Assessment of postural balance in community-dwelling older adults - methodological aspects and effects of biofeedback-based Nintendo Wii training. Danish Medical Journal, 61(1), B4775.

Kang HG, Costa MD, Priplata AA, Starobinets OV, Goldberger AL, Peng CK 2009. Frailty and the degradation of complex balance dynamics during a dual-task protocol. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 64(12), 1304-1311. doi: 10.1093/gerona/glp113

King DL, Zatsiorsky VM 2002. Periods of extreme ankle displacement during one-legged standing. Gait & Posture, 15(2), 172-179.

Kuczynski M, Ostrowska B 2006. Understanding falls in osteoporosis: the viscoelastic modeling perspective. Gait & Posture, 23(1), 51-58. doi: 10.1016/j.gaitpost.2004.11.018

Lafond D, Corriveau H, Hebert R, Prince F 2004. Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. Archives of Physical Medicine and Rehabilitation, 85(6), 896-901.

Lajoie Y, Girard A, Guay M 2002. Comparison of the reaction time, the Berg Scale and the ABC in non-fallers and fallers. Archives of Gerontology and Geriatrics, 35(3), 215-225.

Larsson L, Grimby G, Karlsson J 1979. Muscle strength and speed of movement in relation to age and muscle morphology. Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology, 46(3), 451-456.

Laughton CA, Slavin M, Katdare K, Nolan L, Bean JF, Kerrigan DC 2003. Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. Gait & Posture, 18(2), 101-108.

Lee HC, Tsauo JY, Hung JW, Huang YC, Lin SI and the Fall Prevention Initiatives in Taiwan (FPIT) Investigators (2013). Effects of a Multifactorial Fall Prevention Program on Fall Incidence and Physical Function in Community-Dwelling Older Adults With Risk of Falls. Archives of Physical Medicine and Rehabilitation, 94, 606-615.

Lin D, Seol H, Nussbaum MA, Madigan ML 2008. Reliability of COP-based postural sway measures and age-related differences. Gait & Posture, 28(2):337-42. doi: 10.1016/j.gaitpost.2008.01.005.

Lord SR, Castell S, Corcoran J, Dayhew J, Matters B, Shan A 2003. The effect of group exercise on physical functioning and falls in frail older people living in retirement villages: a randomized, controlled trial. Journal of the American Geriatrics Society,51(12), 1685-1692.

Lord SR, Ward JA, Williams P, Anstey KJ 1994. Physiological factors associated with falls in older community-dwelling women. Journal of the American Geriatric Society, 42(10), 1110-1117.

Luchies CW, Alexander NB, Schultz AB, Ashton-Miller J 1994. Stepping responses of young and old adults to postural disturbances: kinematics. Journal of the American Geriatric Society, 42, 506–512.

Maki BE, Cheng KC, Mansfield A, Scovil CY, Perry SD, Peters AL 2008. Preventing falls in older adults: new interventions to promote more effective change-in-support balance reactions. Journal of Electromyography and Kinesiology, 18(2), 243-254.

Maki BE, Holliday PJ, Topper AK 1994. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. 49(2), M72-84.

Manchester D, Woollacott M, Zederbauer-Hylton N, Marin O 1989. Visual, vestibular and somatosensory contributions to balance control in the older adult. Journal of Gerontology, 44(4), M118-M127.

Mansfield A, Maki BE 2009. Are age-related impairments in change-in-support balance reactions dependent on the method of balance perturbation?, Journal of Biomechanics, 42(8), 1023-1031.

Mansfield A, Peters AL, Liu BA, Maki BE 2010. Effect of a perturbation-based balance training program on compensatory stepping and grasping reactions in older adults: a randomized controlled trial. Physical Therapy, 90(4), 476-491. doi: 10.2522/ptj.20090070

Marigold D, Janice J 2006. The relationship of asymmetric weight-beraing with postural sway and visual reliance in stroke. Gait & Posture, 23(2), 249-255.

Mattacola CG, Lebsack DA, Perrin DH 1995. Intertester reliability of assessing postural sway using the chattecx balance system. Journal of Athletic Training, 30(3), 237-242.

McIlroy WE, Maki BE 1996. Age-related changes in compensatory stepping in response to unpredictable perturbations. Journals of Gerontology, 51A, M289–M296.

Medell JL, Alexander NB 2000. A clinical measure of maximal and rapid stepping in older women. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 55(8), M429-433.

Melzer I, Benjuya N, Kaplanski J 2004. Postural stability in the elderly: a comparison between fallers and non-fallers. Age and Ageing, 33(6), 602-607. doi: 10.1093/ageing/afh218

Merlini L, Mazzone ES, Solari A, Morandi L 2002. Reliability of hand-held dynamometry in spinal muscular atrophy. Muscle & Nerve, 26(1), 64-70. doi: 10.1002/mus.10166

Nardone A, Grasso M, Tarantola J, Corna S, Schieppati M 2000. Postural coordination in elderly subjects standing on a periodically moving platform. Archives of Physical Medicine and Rehabilitation, 81(9), 1217-1223. doi: 10.1053/apmr.2000.6286

Nardone A, Siliotto R, Grasso M, Schieppati M 1994. Influence of aging on leg muscle reflex responses to stance perturbation. Archives of Physical Medicine and Rehabilitation, 76(2), 158-165.

Nashner LM, Peters JF 1990. Dynamic posturography in the diagnosis and management of dizziness and balance disorders. Neurologic Clinics, 8(2), 331-349.

Nishiwaki Y, Takebayashi T, Imai A, Yamamoto M, Omae K 2000. Difference by instructional set in stabilometry. Journal of Vestibular Research: Equilibrium & Orientation10(3), 157-161.

Norre ME, Forrez G 1986. Vestibulospinal function in otoneurology. ORL; Journal for Oto-rhino-laryngology and its Related Specialties, 48(1), 37-44.

Pataky Z, Armand S, Muller-Pinget S, Golay A, Allet L 2014. Effects of Obesity on Functional Capacity. Obesity, 22, 56–62. doi:10.1002/oby.20514.

Pijnappels M, Bobbert MF, van Dieen JH 2005. Push-off reactions in recovery after tripping discriminate young subjects, older non-fallers and older fallers. Gait & Posture, 21(4), 388-394.

Pijnappels M, van der Burg PJ, Reeves ND, van Dieen JH 2008. Identification of elderly fallers by muscle strength measures. European Journal of Applied Physiology, 102(5), 585-592.

Prieto T, Myklebust J, Hoffmann R, Lovett E, Myklebust B 2002. Measures of postural steadiness: differences between healthy young and elderly adults. IEEE Transactions on Biomedical Engineering, 43(9), 956-966.

Province MA, Hadley EC, Hornbrook MC, Lipsitz LA, Miller JP, Mulrow CD 1995. The effects of exercise on falls in elderly patients. A preplanned meta-analysis of the FICSIT Trials. Frailty and Injuries: Cooperative Studies of Intervention Techniques. The Journal of the American Medical Association, 273(17), 1341-1347.

Prudham D, Evans JG 1981. Factors associated with falls in the elderly: a community study. Age and Ageing, 10(3), 141-146.

Rocchi L, Chiari L, Cappello A 2004. Feature selection of stabilometric parameters based on principal component analysis. Medical & Biological Engineering & computing, 42(1), 71-79.

Rogers, M. W., Hedman, L. D., Johnson, M. E., Cain, T. D., & Hanke, T. A. (2001). Lateral stability during forward-induced stepping for dynamic balance recovery in young and older adults. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 56(9), M589-594.

Rogers MW, Johnson ME, Martinez KM, Mille ML, Hedman LD 2003. Step training improves the speed of voluntary step initiation in aging. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 58(1), 46-51.

Romberg M 1853. Manual of Nervous Diseases of Man. London.

Rosengren BE, Ribom EL, Nilsson JA, Mallmin H, Ljunggren O, Ohlsson C 2012. Inferior physical performance test results of 10,998 men in the MrOS Study is associated with high fracture risk. Age and Ageing, 41(3), 339-344. doi: 10.1093/ageing/afs010

Samper-Ternent R, Karmarkar A, Graham J, Reistetter T, Ottenbacher K 2012. Frailty as a predictor of falls in older Mexican Americans. Journal of Aging and Health, 24(4), 641-653. doi: 10.1177/0898264311428490

Shimada H, Obuchi S, Furuna T, Suzuki T 2004. New intervention program for preventing falls among frail elderly people: the effects of perturbed walking exercise using a bilateral separated treadmill. American Journal of Physical Medicine & Rehabilitation, 83(7), 493-499.

Stel VS, Smit JH, Pluijm SM, Lips P 2003. Balance and mobility performance as treatable risk factors for recurrent falling in older persons. Journal of Clinical Epidemiology, 56(7), 659-668.

Stelmach G, Phulips J, DiFabio R, Teasdale N 1989. Age, functional postural reflexes, and voluntary sway. Journal of Gerontology, 44(4), B100-B106.

Studenski S, Hayes RP, Leibowitz RQ, Bode R, Lavery L, Walston J 2004. Clinical Global Impression of Change in Physical Frailty: development of a measure based on clinical judgment. Journal of the American Geriatrics Society, 52(9), 1560-1566. doi: 10.1111/j.1532-5415.2004.52423.x

Tallon G, Blain H, Seigle B, Bernard PL, Ramdani, S 2013. Dynamical and stabilometric measures are complementary for the characterization of postural fluctuations in older women. Gait & Posture, 38(1), 92-96. doi: 10.1016/j.gaitpost.2012.10.021

Thelen DG, Wojcik LA, Schultz AB, Ashton-Miller JA, Alexander NB 1997. Age differences in using a rapid step to regain balance during a forward fall. 52(1), M8-13.

Tinetti M 1994. Prevention of falls and fall injuries in elderly persons: a research agenda. Preventive Medicine, (23), 756-762.

Topper AK, Maki BE, Holliday PJ 1993. Are activity-based assessments of balance and gait in the elderly predictive of risk of falling and/or type of fall? Journal of the American Geriatrics Society, (41), 479-487.

Tsai YC, Hsieh LF, Yang S 2014. Age-related changes in posture response under continuous and unexpected perturbation. Journal of Biomechanics, (47), 482-490.

Van Dieen JH, Pijnappels M, Bobbert MF 2005. Age related intrinsic limitations in preventing a trip and regaining balance after a trip. Safety Science, 43(7), 437-453.

Vincent HK, Raiser SN, Vincent KR 2012. The aging musculoskeletal system and obesity-related considerations with exercise. Ageing Research Reviews, 11(3), 361-373. doi: 10.1016/j.arr.2012.03.002

Voorhees RL 1989. The role of dynamic posturography in neurotologic diagnosis. The Laryngoscope, 99(10 Pt 1), 995-1001.

Wojcik LA, Thelen DG, Schultz AB, Ashton-Miller JA, Alexander NB 1999. Age and gender differences in single-step recovery from a forward fall. Journals of Gerontology, 54A, M44–M50.

Wolfson L, Whipple R, Derby CA, Amerman P, Nashner L 1994. Gender differences in the balance of healthy elderly as demonstrated by dynamic posturography. Journal of Gerontology, 49(4), M160-167.

Woollacott MH, Shumway-Cook A 1990. Changes in posture control across the life span-a systems approach. Physical Therapy, 70(12), 799-807.