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Development of an objective balance assessment method for purposes of telemonitoring and telerehabilitation in elderly population

ZLATKO MATJAČIĆ[1], KLEMEN BOHINC[2] & IMRE CIKAJLO[1]

[1]*Institute for Rehabilitation, Republic of Slovenia, Ljubljana, Slovenia, and* [2]*University of Ljubljana, College of Health Studies, Ljubljana, Slovenia*

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Abstract

Purpose. Reliable assessment of balance abilities and determination of the likelihood of falling in the elderly requires a skilled clinician to guide and assist the individual throughout the scoring of a suitable balance assessment method. The most widely used clinical instrument is the Berg Balance Scale (BBS). The aim of this study was to develop an objective balance assessment measure that would correlate well with BBS and could thus be used to test balancing abilities remotely.

Methods. Twenty elderly individuals were divided into two groups: fallers and non-fallers based on their falling records. Balance abilities were assessed by means of BBS as well as through analysis of peak amplitude of center-of-pressure (COP) responses that followed induced-sway, provoked by a moveable standing frame in the medio-lateral plane. An independent *t*-test was used to compare BBS scores and COP based measures between both groups. Additionally, correlation between both tests was determined by use of the Pearson correlation coefficient.

Results. Fallers exhibited significantly lower BBS scores as well as significantly lower peak values of COP responses. The coefficient of correlation between both tests was relatively high (0.68) and statistically significant.

Conclusion. The high degree of correlation between both tests implies that the proposed objective balance testing apparatus and methods could be used for remote assessment of balance abilities in the elderly, which has implications for the development of home-based mobility training programs.

Keywords: *Elderly, balance, telerehabilitiation*

Introduction

With advancing age, one of the critical issues related to safe and independent mobility is the deterioration of balance and postural control. Adequate functional balancing and postural control/reactions are of utmost importance, also to prevent falls that may have serious consequences [1]. Several studies that examined the effects of various exercise programs that addressed standing balance, gait, co-ordination and functional exercises as well as muscle strengthening [2,3] have shown that regular exercise improves balance abilities and reduces the number of falls in the elderly; however, these effects are not long-lasting. Typically, exercise programs are delivered either at homes for the elderly or in an institutionalised environment, which is costly and for many of the elderly inaccessible. Recently, we developed and evaluated technology that enables efficient balance training in a fall-safe environment that can be practiced also at individual homes of the elderly population [4]. However, to run the developed balance training program at homes of individuals who were identified to be at risk of falling an objective balance assessment method is needed for monitoring the training progress.

In several studies, researchers were interested in testing postural performance in the elderly to develop simple balance tests that could discriminate between the fallers and non-fallers and furthermore to assess the likelihood of falling in elderly individuals. Lajoie and Gallagher [5] assessed the Berg Balance Scale (BBS) and simple reaction time tests in groups of fallers and non-fallers and developed a regression model which could be used to predict the probability of falling based on an individual BBS score. Their

Correspondence: Zlatko Matjačić, PhD, Associate Professor, Head of Research Unit, Institute for rehabilitation, Republic of Slovenia, Linhartova 51, SI-1000 Ljubljana, SLOVENIA. Tel: +386-1-47-58-159. Fax: +386-1-43-72-070. E-mail: zlatko.matjacic@mail.ir-rs.si

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results, as well as results of a similar study by Shumway-Cook et al. [6], have shown that BBS is one of the most effective predictors for falls. It has been experimentally determined on a larger group of elderly persons that a BBS score between 40 and 50 corresponds to a probability of falling between 10 and 80%. BBS scores below 30 represent 100% risk of falling. A major drawback of BBS is that the assessment requires at least 30 min by a skilled professional who guides and assists an individual during testing. Alternative, objective methods for balance assessment are related to measurements of center-of-pressure (COP) during quiet or perturbed stance. Lord et al. [7] looked into spontaneous-sway characteristics of the elderly during quiet standing on force platforms and found that potential fallers may exhibit up to three times greater sway amplitudes in the medio-lateral (ML) plane as measured by the excursions of COP. Maki et al. [8] utilised induced-sway methods (moving platform) to discriminate between fallers and non-fallers and found significant age-related decreases in stability that were greater in induced-sway measures than those in the spontaneous-sway measures, indicating that induced-sway testing may be more sensitive. Maki et al. [8] also pointed out that the postural performance in ML plane is most indicative in assessing the likelihood of falling. However, the question of safety as well as the high cost of instrumentation impedes use of platform-induced test in clinical as well as home environment.

In our previous work, we have developed a mechanical apparatus and methods that are suitable for fall-free balance training during standing [9]. Because the mechanical apparatus enables training in fall-free conditions it is suitable for use in clinical as well as home environment. Additionally, the mechanical apparatus was equipped with four low-cost electrical motors that enable repeatable and random application of mechanical perturbations in eight directions in the transversal plane of motion applied at the waist of a subject who is standing on two force platforms. A variety of different objective measures of resulting postural responses, most notably peak amplitude of COP excursions following perturbations, were derived [10]. The results of several case tests of postural responses in chronic post-stroke individuals indicated that BBS and peak amplitude responses of COP following induced-sway postural responses in ML plane may provide similar information on postural abilities of tested individuals. The lower values of BBS correlated well with lower values of peak COP excursions in individuals with poorer balancing abilities, whereas higher values of BBS correlated well with higher values of peak COP excursions in individuals with better balancing abilities.

It would be a significant step forward if we could test balancing abilities by an objective measurement, which is easy to administer in a fall-free environment. This would enable balance training and monitoring remotely, thus enabling maintenance of adequate mobility skills at homes of the elderly and disabled population. Furthermore, since it seems from the literature that the BBS is the most commonly accepted instrument for balance assessment as well as identification of fall-risk among clinicians, a candidate for an objective balance assessment instrument should correlate well with BBS to enable healthcare professionals to make a meaningful comparison upon which an adequate training program could be managed.

The aim of this study was to explore induced-sway postural responses in the ML plane in the two groups of elderly persons: a group of individuals without a history of falling and a group of individuals with a falling record. By choosing the two tested groups that markedly differ in their balance performance, where a significant difference in their BBS scores could be expected, we could explore the hypothesis, based on the results of our previous study in the stroke population [10], that also peak amplitude responses of COP should be significantly different between both groups. An additional objective of the study was to relate BBS scores and the COP-based balance measure to test the degree of correlation between the two tests and thus determine whether the COP based balance measure could be used in remote monitoring of progress in balance abilities in the elderly who practice balance training at their homes with the developed mechanical apparatus [9].

Materials and methods

Subjects

In our study, 20 elderly subjects volunteered from the local elderly home and represent a sample of convenience. All subjects were able to maintain quiet stance for at least one minute, they had no diagnosis of neurological diseases and all successfully passed the Mini-Mental State Examination, which is a short test of cognitive abilities [11]. Additionally, based on the data log on falls maintained by the physiotherapy service at the local elderly home, the subjects were divided into two groups. The non-fallers group was composed of eight women and two men who had no record of falling, with average age 75.6 ± 10.2 years (mass 71.4 ± 8.6 kg, height 164 ± 4.8 cm), whereas the fallers group was composed of 10 women who experienced at least one reported and recorded fall, and whose average age was 84.6 ± 4.2 years (mass 75.7 ± 12.7 kg, height 163 ± 6.26 cm). The study was approved by the national ethics committee, and all subjects gave informed consent.

Berg balance scale

The assessment of postural control and balancing abilities was assessed by a Berg Balance Scale (BBS) that has proven to be reliable and valid for the elderly population [12]. The test was subjectively scored by an experienced physiotherapist who was blinded to the subjects' falls history. The BBS assessment took place before the assessment of induced-sway postural responses.

Equipment

Induced-sway postural responses were generated by means of the computer-controlled mechanical apparatus shown in Figure 1. The apparatus is described in detail by Cikajlo and Matjačić [10]; here, we provide only a brief description. The apparatus is a standing frame made of aluminum and fixed to the base through compliant springs enabling movement in two degrees of freedom: anterior–posterior (AP) and ML sway. On the top of the standing frame, a wooden table with a safety belt enables firm and comfortable contact of the standing subject at the level of the pelvis. In this way, the subject's pelvis follows the inclinations of the standing frame in the transverse plane. Two battery powered electric motors (Iskra Avtoelektrika d.d., Šempeter, Slovenia), connected via ropes to the frame, were used to generate postural perturbations in two directions in the ML plane: right (RT) and left (LT). Each electrical motor delivered constant torque during the selected duration of perturbation. The realisation of perturbation and movement of the standing frame was managed on the command from

Figure 1. Schematic presentation of the apparatus for assessment of postural responses. Although the apparatus enables application of perturbations in both AP and ML planes, only perturbations in ML plane were utilised in this study.

the personal computer. The command was realised as a pulse generated by the multipurpose PCI board (NI 6259, National Instruments, Austin, Texas) and dedicated computer software. To perturb the frame in one of the two directions the appropriate electric motor winded up the rope and pulled the frame away from its upright position. This led to a corresponding perturbation being applied to the frame and, consequently, to the subject standing in the frame (Figure 1). Participating subjects stood with each foot on separate force plates (AMTI OR6-5, AMTI, Watertown, MA) assessing 6-DOF data (three forces, three moments, filtered within the AMTI amplifier). Data assessment (sampled $F_s = 100$ Hz) was managed via the developed Matlab (The MathWorks, Natick, MA) software based graphical user interface controlling the multipurpose PCI board.

Protocol

Subjects were instructed to maintain the upright posture with eyes open and gaze directed forward while standing barefooted in the perturbation apparatus. The subjects were instructed to assume stance with their legs in parallel, while the distance between feet was approximately the width of the pelvis. The subjects were instructed to recover upright position after each perturbation. The subjects were allowed to hold the table, which moved together with the frame. The height of the table was adjusted for each individual. The perturbation direction and the perturbation commencement were defined randomly, but within 1 s after the operator pressed the button. The imposed perturbation provoked a pull on the participating subject that lasted 1 s. The perturbation intensity was set to 3 Nm constant torque of the motor. The total assessment time was set to 6 s. Each subject underwent eight trials, four trials for each perturbation direction (LT, RT). For each perturbation trial, a set of six DOF data (forces and moments in AP direction, medial-lateral direction and vertical axis) for each foot were recorded using two force platforms. The data assessed were used to compute the common COP [10].

Data analysis

Data assessed from both force platforms were filtered (4th order Butterworth filter, 15 Hz cut-off frequency) and used to calculate the common COP, thus forming a postural response. For each perturbation direction, mean responses were calculated from four trials. Examples of COP trajectories for both perturbation directions are shown in Figure 2.

As we were interested only in the automated part of the postural response, the amplitude of the first peak was determined by a computer algorithm [7] in COP trajectories for both ML perturbation directions, relatively to the values of COP before perturbation commencement (Figure 2).

Mean values and standard deviations for each tested group (fallers and non-fallers) were calculated for BBS; and peak amplitude responses (PAR_ML) for each perturbation direction separately.

Statistical analysis

An independent *t*-test was used to test the differences between both groups in terms of age, body mass and height. The independent *t*-test was used to compare the means of BBS and peak amplitude responses (PAR_ML) for each perturbation direction separately. The Pearson correlation coefficient between the BBS and the peak amplitude responses (PAR_ML) was calculated to explore the correlation between tested balance measures.

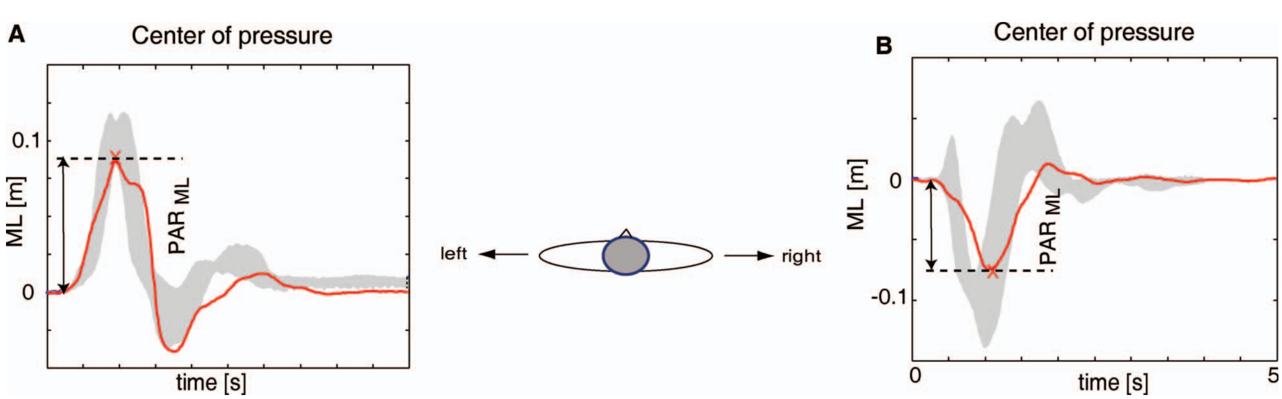

Figure 2. COP responses assessed after perturbations delivered in (A) the left (LT) and (B) right (RT) directions. Shaded area shows responses assessed in a group of young individuals obtained in a previous study [7]. Thin lines show typical responses from a subject in the non-fallers group. Peak amplitude response values (PAR) are indicated.

Results

There were no statistically significant differences between both groups in terms of age ($p = 0.08$), body mass ($p = 0.37$) and height ($p = 0.85$).

Figure 3 shows the mean values and standard deviations for BBS scores (minimal value 0; maximal value 56). The group of non-fallers scored 51.5 ± 3.28 (95% confidence interval 51–52) points while the group of fallers scored 33.87 ± 5.84 (95% confidence interval 34.41–36.19). The difference between both groups is statistically significant ($p < 0.001$).

Figure 4 shows the absolute mean values and standard deviations for the peak amplitude COP responses for both perturbation directions (LT and RT) and for both groups of subjects. The values of PAR_ML for the group of non-fallers were 7.4 ± 1.9 cm (95% confidence interval 6.04–8.77 cm) for the LT perturbation direction, and 7.78 ± 2.52 cm (95% confidence interval 5.9–9.6 cm) for the RT perturbation direction. The values of PAR_ML for the group of fallers were 5.4 ± 1.7 cm (95% confidence interval 4.22–6.65 cm) for the LT perturbation direction, and 5 ± 1.6 cm (95% confidence interval 3.86–6.15 cm)

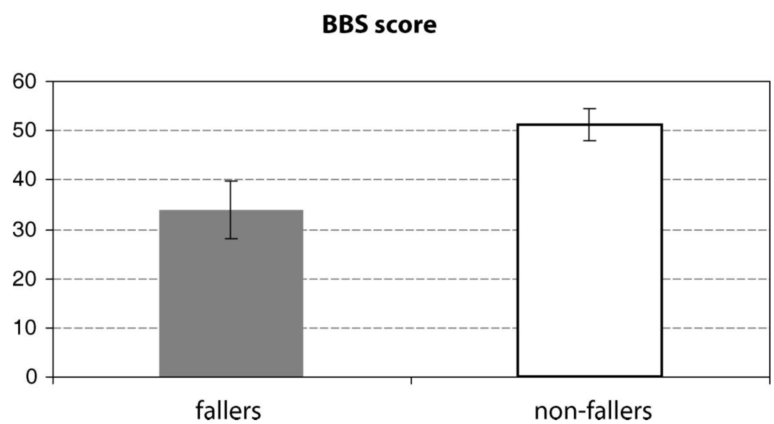

Figure 3. BBS scores (mean values and standard deviations) for both groups of subjects.

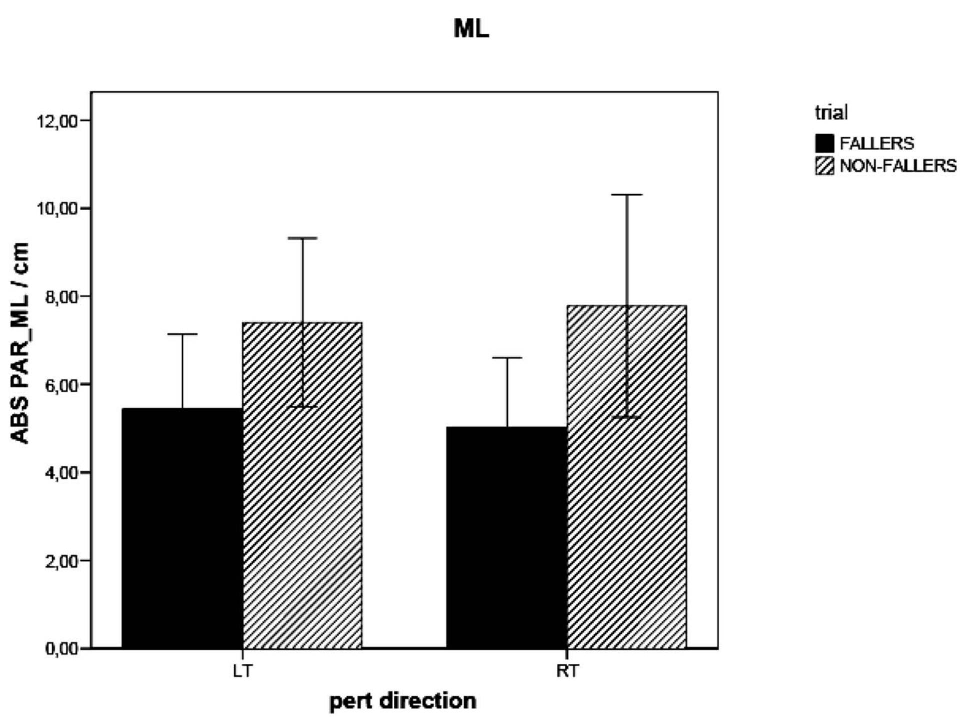

Figure 4. Absolute mean values and standard deviations of peak amplitude responses PAR_ML for each perturbation direction (LT and RT) and for both groups of subjects.

for the RT perturbation direction. We can observe higher values for the group of non-fallers for both perturbation directions. These differences are statistically significant for both perturbation directions (LT, $p = 0.025$ and RT, $p = 0.009$). We have also tested whether there exist any statistically significant differences within both groups of subjects with respect to perturbation direction, which was found not to be the case (fallers, $p = 0.846$, non-fallers, $p = 0.179$). This enabled us to calculate a single variable derived from postural responses, which is composed as a mean value of responses in both perturbation directions.

Figure 5 shows a plot of mean values of both perturbation directions (LT and RT) of peak amplitude COP responses in ML direction *versus* BBS score for both perturbation directions for all subjects. The Pearson correlation coefficient between both variables is relatively high and statistically significant. We can notice that BBS very distinctively separates both tested groups. We can also notice some overlap between both tested groups of subjects when observing the parameter derived from PAR_ML responses. However, most of the subjects from the fallers group had a result below six, while most of the subjects from the non-fallers group had a result above six.

Discussion

Falls and fear of falling represent serious threats to the health and quality of life in the elderly. Balance control and postural reactions deteriorate with age, therefore novel techniques for balance training and assessment of fall-risk, preferably such that can be reliably introduced at the home of an individual, are needed to prolong independent living of the elderly population at their homes.

In the present study, we examined postural responses as reflected in COP trajectories following perturbations delivered in the ML plane to the waist in a fall-safe environment. The results of our study show clear and statistically significant differences in peak amplitude responses of COP in the ML plane between the two groups tested. Both groups significantly differed in BBS score, which is in agreement with the findings of other studies [5,6]. The rather high correlation between the peak amplitude responses of COP following perturbations in ML direction, and the BBS scores for all subjects pooled together indicate that the experimental protocol used in this study may be applied as one of the tools to assess balance in elderly individuals, which could be administered remotely. The information obtained in such a way could give an estimate on the balancing

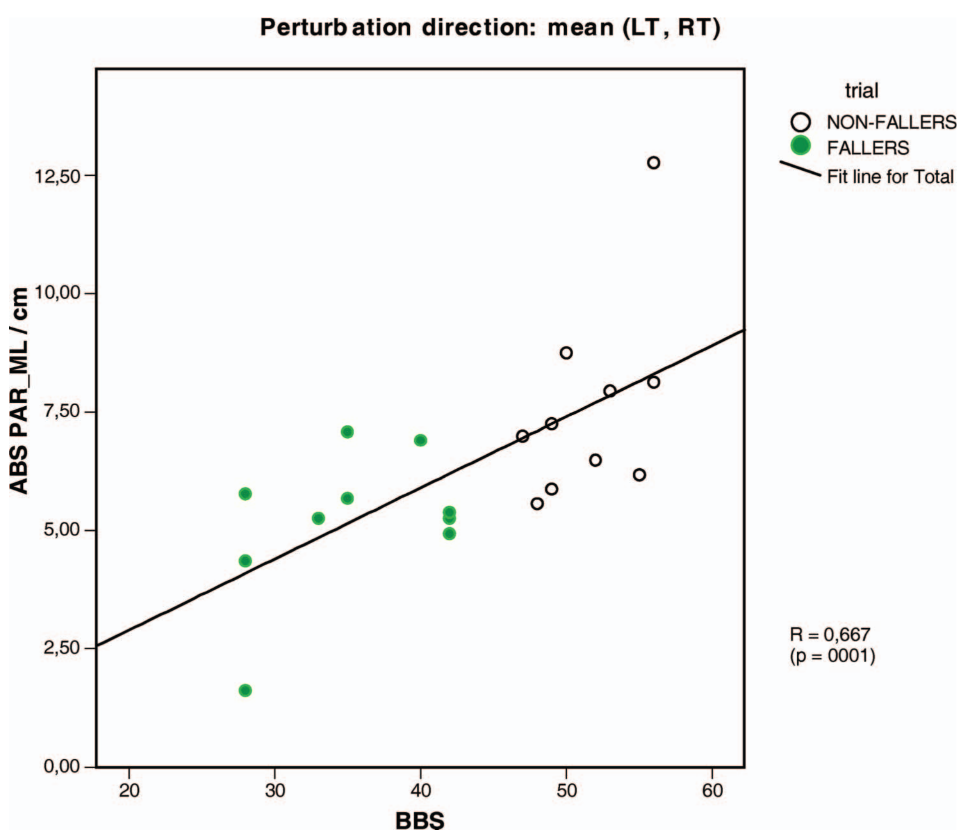

Figure 5. Correlation between the BBS and the proposed objective balance assessment measure – peak amplitude response in ML.

abilities of a particular tested individual, and when combined also with visual observations assessed over a bi-directional video link of a user performing standardised tasks, could provide a reliable assessment of the current status of balance abilities and progress of training. This could facilitate development of various remotely supervised balance training and assessment services. On the other hand, the derived testing protocol could also be used in the clinical environment to test more frequently the progress of balance training, because the induced-sway balance test used in this study takes only few minutes.

Numerous studies have indicated that greater reaction times, poorer tactile sensitivity, greater visual field dependence, diminished muscle strength and greater body sway during quiet standing, especially in the ML direction, accompany deteriorated postural abilities in the elderly [1,5–8]. In this respect, it is important to test postural abilities in dynamic conditions, provoked by external perturbations, where diminished factors that influence balance abilities necessitate selection of an appropriate coping strategy. In bipedal stance, humans cope with unexpected perturbations through a continuum of postural strategies that span between two extreme cases [13,14]; (1) by controlling displacement of COP that oscillates around the vertical projection of COM, which is predominantly facilitated by adequate hip abductors' activity and (2) by controlling shear forces that result as a consequence of appropriate trunk muscles' activity. In the first case, little movement can be observed, which is characteristic for younger adults, whereas in the second case marked sways of body segments accompany postural responses, which is characteristic of the elderly population. The results of our study show that the elderly with poorer balance abilities, as assessed by BBS scores, rely less on the controlling displacement of COP to arrest the movement of COM, and consequently utilise more balancing activity of the trunk.

The study design and selection of subjects was based on the information on falls, which is an important indicator of balance abilities in each individual. In this way, we were able to explore whether the proposed testing protocol can provide similar information as BBS, which was indeed the case. However, neither the proposed testing protocol nor BBS can give a definitive answer as to whether a particular subject is in risk of falling. This is because only the probability of a falling event can be assigned to a particular score. This means that both tests have an outcome range in which there exists uncertainty about the likelihood of a falling event; in BBS this range is from 35 to 50 points, while in the proposed COP based balance measure it appears from the results that this range is between 5 and 7 cm. Both instruments can, however, be used to monitor the progress in balance abilities following a period of balance training.

There are some limitations of the study that are related to the selection of subjects which represent a sample of convenience. As the subjects were divided into two groups, based on the self-reported fall records-which may not reflect the real situation, as many falls may remain unreported-there may be a concern regarding the suitability of both groups. However, the significant difference in BBS scores between the two tested groups does show that the two groups of subjects markedly differed in their balancing abilities, which enabled us to explore the hypothesis posed in the Introduction. Another concern could be the device setup, which by providing a fall-free testing environment, could possibly have an influence on the organisation of elicited postural responses. We have shown in one of our earlier studies, using the described setup, that the postural responses elicited by the device in conditions when the frame is fixed around the subject's waist were practically identical to the situation when only a part of the frame was used in such a way as only to apply perturbation and afterwards detach from the waist of the standing subject [15].

The good correlation between both balance measures suggests that the proposed mean peak amplitude COP response measure could be used as a reliable indicator of potential improvement of balancing abilities in each individual who practices balance training in the developed mechanical apparatus according to a suitable treatment program, such as the one described by Matjačić and Zupan [4]. However, a more extensive study is needed, investigating how much information about an older person's balance can be provided by the proposed instrument, which would provide some guidelines as to what kind of users could benefit from the use of the device described in this article.

Conclusion

The results of our study have shown that there exists a strong correlation between balancing abilities as assessed by BBS and objective measurements of peak amplitude responses of COP trajectories following perturbations applied at the waist in the ML plane. Because the developed testing apparatus provides a fall-free environment, it may be used as a remote assessment instrument that could enable the telerehabilitation service of balance at homes of the elderly in need of such a service. In such a case, the force platforms used in our study could be replaced by inexpensive load cells.

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References

1. Bloem BR, Steijns JA, Smits-Engelsman BC. An update on falls. Curr Opin Neurol 2003;16:15–26.
2. Weerdesteyn V, Rijken H, Geurts AC, Smits-Engelsman BC, Mulder T, Duysens J. A five-week exercise program can reduce falls and improve obstacle avoidance in the elderly. Gerontology 2006;52:131–141.
3. Howe TE, Rochester L, Jackson A, Banks PM, Blair VA. Exercise for improving balance in older people. Cochrane Database Syst Rev 2007;4:CD004963.
4. Matjačić Z, Zupan A. Effects of dynamic balance training during standing and stepping in patients with hereditary sensory motor neuropathy. Disabil Rehabil 2006;28:1455–1459.
5. Lajoie Y, Gallagher SP. Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the activities-specific balance confidence (ABC) scale for comparing fallers and non-fallers. Arch Gerontol Geriatr 2004;38:11–26.
6. Shumway-Cook A, Baldwin M, Polissar NL, Gruber W. Predicting the probability for falls in community-dwelling older adults. Phys Ther 1997;77:812–819.
7. Lord SR, Rogers MW, Howland A, Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. J Am Geriatr Soc 1999;47:1077–1081.
8. Maki BE, Holliday PJ, Fernie GR. Aging and postural control: a comparison of spontaneous- and induced-sway balance tests. JAGS 1990;38:1–9.
9. Matjačić Z, Rusjan Š, Stanonik I, Goljar N, Olenšek A. Methods for dynamic balance training during standing and stepping. Artif Organs 2005;29:462–466.
10. Cikajlo I, Matjačić Z. A novel approach in objective assessment of functional postural responses during fall-free perturbed standing in clinical environment. Technol Health Care 2007;15:181–193.
11. Cockrell JR, Folstein MF. Mini-mental state examination (MMSE). Psychopharmacol Bull 1988;24:689–692.
12. Berg KO, Wood-Dauphinee SL, Williams JI. Measuring balance in elderly: validation of an instrument. Can J Public Health 1992;83 (Suppl 2):S7–S11.
13. Winter DA. Human balance and posture control during standing and walking. Gait Posture 1995;3:193–214.
14. Horak FB, Nashner LM. Central programming of postural movements: adaptation to altered support-surface configurations. J Neurophys 1986;55:1369–1381.
15. Matjačić Z, Voigt M, Popović D, Sinkjaer T. Functional postural responses after perturbations in multiple directions in a standing man: a principle of decoupled control. J Biomech 2001;34:187–196.