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Biomechanical analysis of dynamic balance

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Abstract

Background and Purpose

Balance represents one of the most basic aspects in both sports and everyday activities like running, jumping and walking. Several factors such as injuries, anthropometric variables, sex, biofeedbacks and neurodegenerative processes as Parkinson's disease (PD) might negatively influence balance performances. The evaluation of balance provides essential information about neuromuscular and skeletal systems. In this regard, several postural control assessments have been used to evaluate dynamic balance such as force plates and functional tests due their reliability and validity. However, due the multifaceted features of this ability, new approaches are needed to accurately evaluate and measure dynamic balance performances. During large-scale evaluations, inexpensive, easy, administrable and accurate tools such as computerized Wobble Boards (WBs) have been suggested to be reliable in the evaluation of this ability in several populations. Therefore, the aims of this project were to measure WB performances and to evaluate the effect anthropometrics, sex, visual biofeedback (VBF) and PD process on dynamic balance performances assessed by computerized WB.

Methods

The project is organized in three phases, as follows:

I. The first part of the present project aimed to measure wobble performance in individuals with unilateral chronic ankle instability (CAI). For the study, 39 healthy and 20 unilateral CAI recreationally active young adults were enrolled. subjects were required to perform a 3-minute familiarization, followed by 1-minute rest in sitting position, standing on the WB in a single leg stance position, finding a comfortable and central position with the knee slightly bent and keeping the hands on the hips. The balance test consisted of three 30-second trials per limb with 1-minute sitting rest in between. During the test each subject was asked to focus on the motion marker (MM) displayed on the monitor placed at eye level 2-meter in front of him or her and to keep it inside the target zone (TZ) as long as possible. Visual markers were also applied to the participants' base of the fifth metatarsal, lateral malleolus, lateral joint line of the knee, anterior superior iliac spine and acromion process. All WB trials were recorded by a video camera. On each video, a researcher measured joint angles from the beginning to the end of the test trial using the visual markers as references. Hip angular-displacement was measured as the angle between the acromion process and lateral joint line of the knee with the greater trochanter serving as the fulcrum. Knee angular displacement was measured as the angle between the greater trochanter and lateral malleolus with lateral knee joint serving as the fulcrum. Ankle angular-displacement was measured as the angle between a line from the lateral knee joint and the base of the fifth metatarsal with the lateral malleolus being the fulcrum.

II. The influence of anthropometrics, sex, and VBF on human dynamic balance is well documented, however no study has yet investigated on the effect and the interaction of the above-mentioned factors on computerized WB. For this purpose, the second part of this project investigated the effect of anthropometric characteristics, sex, and VBF on the WB balance performances during double leg stance. During this phase, 27 subjects (14 females, 13 males) were required to perform 3-minute of free practice on the WB followed by three 30-second double leg stance trials and 1-minute sitting recovery in between. Subjects were asked to perform WB test during two conditions. For the VBF condition subjects were asked to keep visual focus on the MM showed on the display and try to keep it inside the TZ as long as they could within 30 seconds; and for without Visual Biofeedback (NVBF) one, subjects were instructed to look at a fixed point on a black board, keeping visual focus on a marking in front of them and instructed to maintain the WB as flat and still as possible for as long as possible within the recording period of 30 seconds.

III. Regarding the third part, a protocol study was developed to evaluate dynamic balance and fine motor skills performances assessed by WB and Grooved Pegboard test (GPT) in PD patients. Recruited subjects will be enrolled for the single-blind study and randomly allocated in two groups: PD group and Control group (CON group). PD group will participate in the intervention program; CON group will participate in a stretching program. Before (PRE) and after (POST) the intervention program (combined balance and fine motor skills exercises) both groups will perform the WB and GPT tests in a randomized order. The WB evaluation will be performed for both lower and upper limbs. During lower limb tests, subjects will be required to be in a seated position on a chair with back support with the hands resting on their legs and WB placed in front of the chair. During upper limb tests, subjects will be in a seated position, with the tested limb placed at 90° on the WB and the contralateral one (limb not performing the test) resting on the lower limb of the same side. The WB will be placed on a table and the monitor at eye level. Regarding the GPT, the subjects will familiarize themselves with the task by filling only the first top row. Subsequently, subjects will be instructed to insert pegs one by one into the pegboard, as fast as possible, completing the rows from left to right for the right limb and from right to left for the left limb, from top to bottom (with 1-minute recovery in between). Subjects will be free to perform trials when they prefer. Only the dominant hand will be assessed and all subjects with PD will perform the GPT two times. The recording time will start when subjects take the first peg and will stop when the last peg is inserted.

For all tests, the starting limb and the order of conditions will be randomly chosen. Lastly, to avoid any balance and stability provided by shoes, all testing procedures were performed barefoot.

Results

Results showed that ankle and knee angular-displacement parameters, body height and lower limb length were the major predictors of the WB performance and played major roles on the accuracy of the extrapolated equation models. Additionally, the extrapolated equation may provide different methods to quantify the WB performance and accurately detect the injured limb in individuals with unilateral CAI. VBF improved dynamic balance on the WB with respect to the condition NVBF. When investigating the effect of anthropometrics variables, sex, and their interactions on the conditions, a significant main effect of the lower limb/height ratio (HTR) sex, and their interaction on the condition without visual biofeedback was found. Moreover, significant effects were found for sex and body mass and sex and moment of inertia in the VBF condition. Finally, it was hypothesized that computerized WB would be useful to detect dynamic balance and fine motor skills in PD subjects.

Conclusion

The computerized WB used in this project is reliable and valid to assess subjects with unilateral CAI. The extrapolated equations quantify the WB performance and accurately detect the injured limb in individuals with unilateral CAI. The WB measures were influenced by anthropometrics, sex and feedbacks, confirming that dynamic balance performances on the WB are affected by other sources of variability. Since WBs are easy to set and to interpret, they have the potential in screening, monitoring and quantifying the progression of balance performances. Moreover, the affordability and transportability of WBs are key factors during filed evaluations, making data collection on balance performances feasible for health specialists and/or coaches looking for inexpensive, portable, reliable, and valid assessment tools. Lastly, results from the present project could have an impact on training and evaluations protocols, especially when several populations such as children, athletes, older adults, people with balance disorders and neurodegenerative disorders are involved.

Literature review

General Introduction

Balance (or equilibrium), in mechanics, is defined as the state of an object when the resultant load actions (forces or moments) acting upon it are zero (Newton's First Law) and is linked to the concept of stability. Similarly in biomechanics, the most used description of "Human Balance", is defined as "the ability to maintain or make adjustments in order to keep the body's Center of Mass (CoM) over the Base of Support (BoS)" [1]. Balance, according to its definition, can also be divided into static, defined as "the capacity to keep the BoS through the minimum motion" and dynamic balance, as "the capacity to keep and/or restore balance during a movement or the capacity to maintain / restore balance on an unstable platform, without external helps" [2]. The major protagonists of balance control are the proprioceptors, located in the skeletal muscles, joint capsules and ligaments. These reveal the position of the body's segments in the space, the muscles' stretch, information about tension and muscular length. Regarding the inputs of the visual, vestibular and proprioceptive systems, each of them varies according to age and context. Based on sensory information from these systems, the central nervous system elaborates and determine continuous postural adjustments via skeletal muscle responses and complex movements on the body's segments position. Impairments on these sensory systems, transmission, elaboration and executive motor control and/or exposure to risk factors may compromise balance control. Simplifying, if the CoM projection line falls outside the BoS, the body is unbalanced, and therefore at risk of fall. Therefore, the maintenance of a correct posture is fundamental for humans.

Although, balance control is directly influenced by the sensorial information, it is also important to give attention to the indirect factors as injuries, anthropometric variables, sex, feedbacks and neurodegenerative diseases as PD that would affect dynamic performances on the WBs. Among several injuries that might influence the balance performances, ankle sprains and consequent residual symptoms such as the development of CAI, are the most recurrent. In fact, approximately 40% [3-4] of individuals that suffer an initial ankle sprain will develop longstanding ankle dysfunction by limiting daily tasks and balance performance. Moreover, CAI is attributed to pathological joint laxity, sensorimotor deficits, or a combination of both factors. Studies [5-8] also focusing on the anthropometric variables have shown that excessive values in body mass [5,9], height [7,10] and lower limb length [10] negatively affected postural control over the lifespan. On the other hand, it is clear that sex is the key biological variable that should be considered in all basic physiological and biological research. However, to date findings are not conclusive, with some studies showing better balance in women [11], and others in men [12], or showing no differences between sex [13]. Postural control can also be influenced by cognitive processes such as VBF [14,15]. VBF can be presented by providing subjects with additional artificial visual information about body movement designed to augment the natural information favouring the adoption of appropriate strategies to keep postural control as steady as possible [15,16]. Regarding neurodegenerative diseases, PD is manly characterized by motor symptoms. Motor symptoms such as tremor disorder and postural changes, result in an increase of rate of falls and dysfunction in ambulation favouring balance impairments, thus negatively affecting the individual's self-care activities and quality of life [17]. Thus, due the complicate nature of dynamic balance, its evaluation has become part of different researches with experimental protocols based on balance control evaluation [2].

To assess dynamic balance performance, several evaluation techniques are available in literature and their difficulty vary from simple standing position to peripheral feedback alteration [18]. Evaluation is carried out through different methodologies, technologies and different levels of balance perception. In clinical and field settings, the assessment of balance can provide accurate and sophisticated information regarding the efficiency of the neuromuscular system. Several postural control assessments have been used to evaluate dynamic balance. Force plates [19] and functional tests [4,20] are commonly used to evaluate balance performances due to their accuracy, validity, and reliability. Furthermore, to quantify the dynamic balance performance and its progression, motion analysis due its accuracy in the data collection and interpretation have been used especially for population with lower limb injuries as CAI [21]. Therefore, new simple approaches [22,23] to accurately evaluate dynamic postural control are needed. Among these new tools, computerized WBs, unstable platform using in training and rehabilitation programs, are recently equipped with accelerometers and connected via USB to a computer showing real-time performances. WBs have been demonstrated to be reliable and valid tools in providing advantages data interpretation regarding dynamic balance performances during several tasks (monopodalic and bipodalic stances, with and without VBF) in several population. Additionally, its specificity, affordability, and transportability are key factors for making the data collection accurate and precise for health specialist and coaches.

Experimental approach to the problem

- *A novel approach to measuring wobble board performance in individuals with chronic ankle instability*

In clinical and field settings, the assessment of balance can provide accurate and sophisticated information regarding the efficiency of the neuromuscular system. However, because of the multifaceted features of the postural control tests, and in some cases the excessive costs of equipment, few study measured dynamic performances. Although specificity, affordability and transportability are key factor for making WB data collection precise and accurate, sometimes, health specialists, scientists and trainers do not own computerized unstable platforms as WB. For this reason, WBs become inadequate tools to measure and quantify dynamic balance ability in CAI population, making motion analysis a potential solution to fill the lack between these limits. Among several motion analysis methods, three-dimensional

(3D) motion analysis is the most used to objectively quantify the WB performances. However, its cost, complexity and the expertise required to data collection and data analysis, 3D analysis does not permit large-scale evaluations, thus limiting its applicability. In this contest, to overcome these limits, two dimensional (2D) motion analyses [24] represent a valid alternative. Despite, the inability to capture rotations and the lack of precision, 2D motion analysis represents a practical, safe, time and a low-cost effective modality in evaluating sagittal plane joint displacements to evaluate movements on the WB in CAI subjects during laboratory and field evaluations. Therefore, 2D motion analysis system approach has the potential to estimate the computerized WB performance in both healthy and CAI individuals, thus providing an alternative tool for specialists.

- *Association between Anthropometric Variables, Sex, and Visual Biofeedback in Dynamic Postural Control Assessed on a Computerized Wobble Board*

In the scientific literature, the influence of anthropometrics, sex, and VBF on human balance is well documented. However, no study has investigated on the effect and the interaction of the above-mentioned factors during dynamic balance performances on the WB. This lack in the literature does not permit to discriminate which source of variability most contribute in dynamic performances assessed by WBs. The evaluation of anthropometrics, sex, and VBF during WB tasks give the opportunity to health specialists, coaches and scientists to accurately detect balance impairments. Moreover, knowing that dynamic performances are negatively or positively affected by these factors, it would be easier to track and monitor training programs and to adapt and tailor individualized balance training protocols.

- *The Effect of a Combined Exercise Program on Postural Control and Fine Motor Skills in Parkinson's Disease: Study Design*

For adults living with neurological impairments as PD, physical activity programs represent the key factor to manage pathology's symptoms and delay the pathological and physical decline. Based on the Parkinson's Exercise Guidelines for People with Parkinson's, studies mainly focused on strength, aerobic, functional balance and coordination programs giving poor attention on combined exercise programs. Considering that, both balance and fine motor skills abilities influence daily life activities and health-related quality of life, it is important introduce combined exercise programs including balance and fine exercises. Thus, the evaluation of these abilities could play a key role in structuring individualized training programs. In this regard, to establish whether combined exercise program has beneficial effect on these abilities, the assessment of dynamic balance and fine motor skills, assessed by WB and GPT, respectively, is performed PRE and POST combined training. Moreover, WB and GPT tests could be practical, inexpensive, administrable and accurate tools to provide essential and useful information, especially in light of the progressive degenerative course of PD, also when home confinement or hospitalization are required.

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Methods

The project was organized in three phases, aiming at:

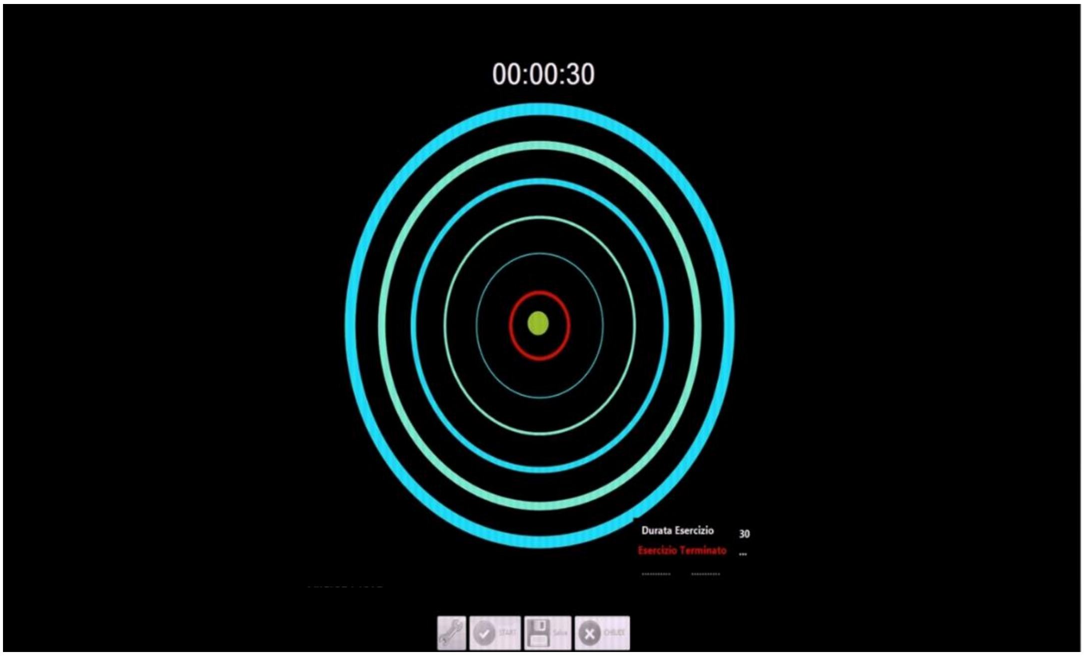
I. measuring wobble performance in individuals with unilateral CAI;
II. investigating the effect of anthropometric characteristics, sex, and VBF;
III. evaluating dynamic balance and fine motor skills performances in PD subjects.

A computerized proprioceptive platform, WB model, was used throughout the three phases of the projects. The computerized Balance Board WSP (Well Sport Project, G.S.J. Services S.r.l., Rome, Italy) is equipped by a triaxial accelerometer (Phidget Spatial 0/0/3 Basic 1041, Phidgets Inc. 2016, Calgary, AB, Canada) measuring ±8g’s (±78 m·s-2) per axis. The platform is composed by a circular wooden surface (diameter 40 cm, height 2 cm) placed on a plastic material semispherical support (diameter 12 cm, height 6 cm) (Figure 1).

Figure 1. Balance Board WSP model wobble board

The platform is connected via USB cable, with a sampling frequency of 200 Hz. The WB tilt (maximal tilt angle = 20◦) angle data is then transmitted to a customized software displaying real time balance performance on a monitor (resolution = 1920 × 1080) through a MM (diameter = 6 mm). The software user interface showed the MM, represented by a yellow circle, a TZ (diameter = 6.5 cm) displayed by a red circle which represented the stability area (0◦ tilt angle), and a countdown of the trial (Figure 2).

Figure 2. Example of wobble board software screen



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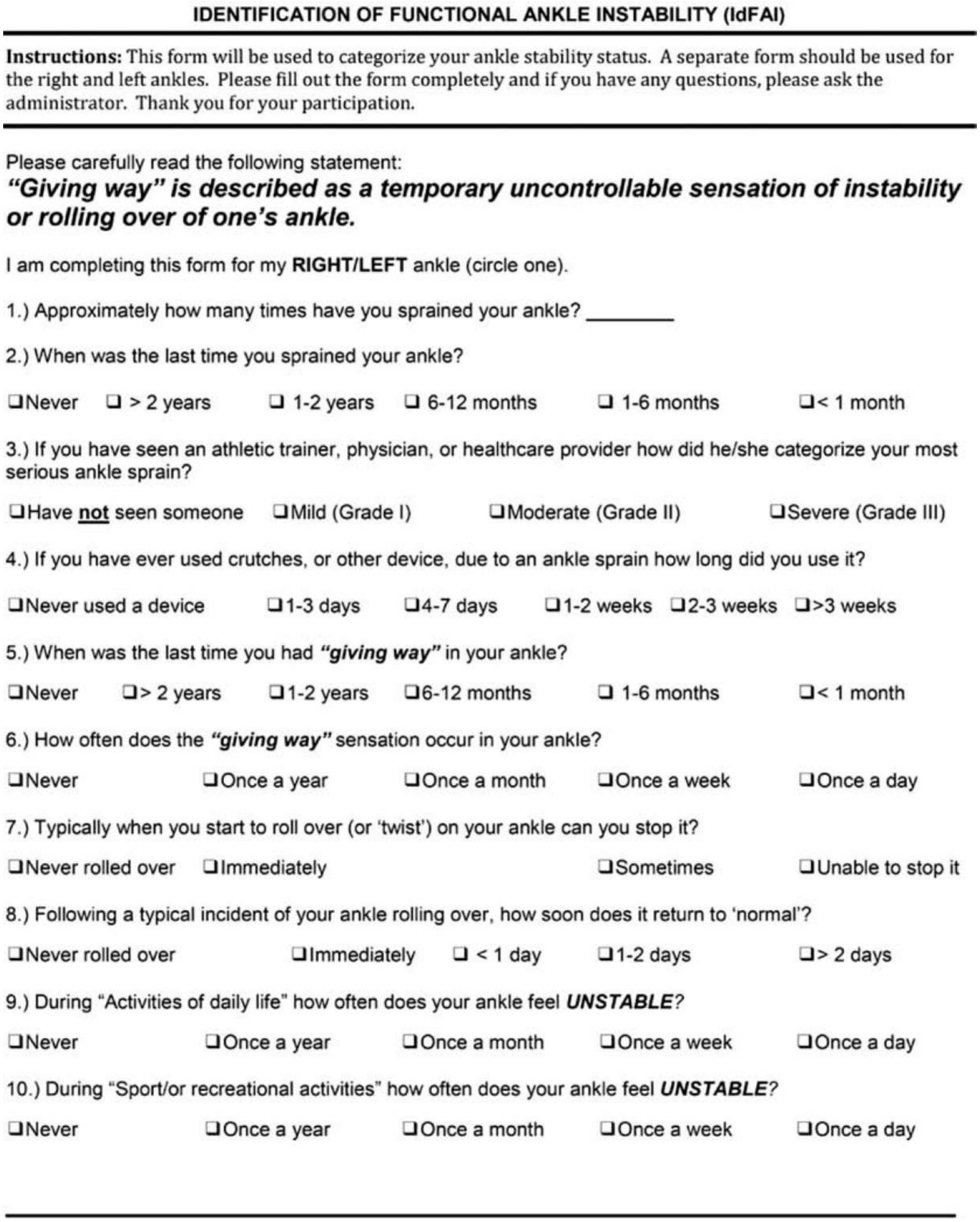
For the first assessment, body mass and height were measured by means of a scale with integrated stadiometer with a precision of 0.1kg and 0.1cm (Seca, model 709, Hamburg, Germany), and body mass index (BMI) calculated. Lower limb length was measured from the anterior superior iliac spine to the most distal part of the medial malleolus by using a tape measure while the subject laid in supine position. The healthy subjects were included if self-reported: no previous injuries, fracture, or surgery of either ankle; no cerebral concussions, lower extremity injuries, vestibular and visual disorders for 3 months before testing; no ear infection, upper respiratory tract infection at the time of the study; no prior balance training. Subjects also completed the Italian version of the Identification of Functional Ankle Instability (IdFAI) questionnaire that consists of ten questions useful to identify subjects with unilateral CAI (Figure 3).

Figure 3. The identification of functional ankle instability questionnaire



IDENTIFICATION OF FUNCTIONAL ANKLE INSTABILITY (IdFAI)

Instructions: This form will be used to categorize your ankle stability status. A separate form should be used for the right and left ankles. Please fill out the form completely and if you have any questions, please ask the administrator. Thank you for your participation.

Please carefully read the following statement:

"Giving way" is described as a temporary uncontrollable sensation of instability or rolling over of one's ankle.

I am completing this form for my **RIGHT/LEFT** ankle (circle one).

1.) Approximately how many times have you sprained your ankle? ________

2.) When was the last time you sprained your ankle?

☐Never ☐ > 2 years ☐ 1-2 years ☐ 6-12 months ☐ 1-6 months ☐< 1 month

3.) If you have seen an athletic trainer, physician, or healthcare provider how did he/she categorize your most serious ankle sprain?

☐Have **not** seen someone ☐Mild (Grade I) ☐Moderate (Grade II) ☐Severe (Grade III)

4.) If you have ever used crutches, or other device, due to an ankle sprain how long did you use it?

☐Never used a device ☐1-3 days ☐4-7 days ☐1-2 weeks ☐2-3 weeks ☐>3 weeks

5.) When was the last time you had ***"giving way"*** in your ankle?

☐Never ☐> 2 years ☐1-2 years ☐6-12 months ☐ 1-6 months ☐< 1 month

6.) How often does the ***"giving way"*** sensation occur in your ankle?

☐Never ☐Once a year ☐Once a month ☐Once a week ☐Once a day

7.) Typically when you start to roll over (or 'twist') on your ankle can you stop it?

☐Never rolled over ☐Immediately ☐Sometimes ☐Unable to stop it

8.) Following a typical incident of your ankle rolling over, how soon does it return to 'normal'?

☐Never rolled over ☐Immediately ☐ < 1 day ☐1-2 days ☐> 2 days

9.) During "Activities of daily life" how often does your ankle feel ***UNSTABLE***?

☐Never ☐Once a year ☐Once a month ☐Once a week ☐Once a day

10.) During "Sport/recreational activities" how often does your ankle feel ***UNSTABLE***?

☐Never ☐Once a year ☐Once a month ☐Once a week ☐Once a day

Unilateral CAI subjects were selected if they self-reported: at least one unilateral ankle sprain, but none within the past 6 weeks; multiple (more than 3) episodes of unilateral ankle giving way within the past 12 months; no previous fracture or surgery of either ankle; no cerebral concussions, lower extremity injuries, visual and vestibular disorders for 3 months before testing; no ear infection, upper respiratory tract infection at the time of the study; and no prior balance training.

For the WB test, subjects had 3-minute of free practice and three 30-second trials per limb with 1-minute sitting rest in between (Figure 4).

Figure 4. Standard one leg stance wobble board test position

Before the testing sessions, visual markers were applied to the participants' base of the fifth metatarsal, lateral malleolus, lateral joint line of the knee, anterior superior iliac spine and acromion process. Trials were recorded by a video camera (Sony Camcorder HDRCX290/B; Sony, Minato, Tokyo, Japan) laterally fixed at 2.30 meters from the subjects and 1 meter above the ground. Videos of all trials were imported on the Dartfish motion analysis software (Dartfish Team Pro 5.5; Dartfish, Fribourg, Switzerland) and hip, knee and ankle angular-displacement data in the sagittal plane were calculated. Hip angular-displacement was measured as the angle between the acromion process and lateral joint line of the knee with the greater trochanter serving as the fulcrum. Knee angular-displacement was measured as the angle between the greater trochanter and lateral malleolus with lateral knee joint serving as the fulcrum. Lastly, ankle angular-displacement was measured as the angle between a line from the lateral knee joint and the base of the fifth metatarsal with the lateral malleolus being the fulcrum.

In phase two, the anthropometric, sex and VBF on WB balance performances during double leg stance assessment was determined. Before starting the testing session, subjects' characteristics were assessed. Body mass and height were measured by means of a scale with an integrated stadiometer with a precision of 0.1 kg and 0.1 cm (Seca, model 709, Vogel & Halke, Hamburg, Germany), and body mass index was calculated. In addition, whole-body moment of inertia was also computed using the following formula: $MI = (3.44 \cdot HT2) + (0.144 \cdot M) - 8.04$. The subjects performed the WB test with the same procedures adopted in the first phase but with different protocol. Subjects performed WB in double leg stance during two conditions: with VBF, where subjects were asked to keep visual focus on the MM showed on the display; and NVBF, looking at a fixed point on a black board (Figure 5).

Figure 5. Standard double leg stance wobble board test position during Visual Biofeedback and without Visual Biofeedback conditions

The leg stances (one and double stance) and VBF and NVBF conditions for the evaluation of dynamic balance on the WB were preferred because they are common and challenging task employed during dynamic exercise training and could be more suitable for the assessment of balance ability.

For the third phase, the evaluation was though for both lower and upper limbs assessed by WB and GPT. The subjects performed the WB test with the same procedures adopted in the first phase but with different protocol. During the test, the TZ displays different motion patterns: clockwise, counterclockwise, antero-posterior, medial-lateral. Subjects are required to be in a seated position to ensure the safety of each PD individual (Figure 6).

Figure 6. Standard lower and upper limb wobble board test position for Parkinson's disease

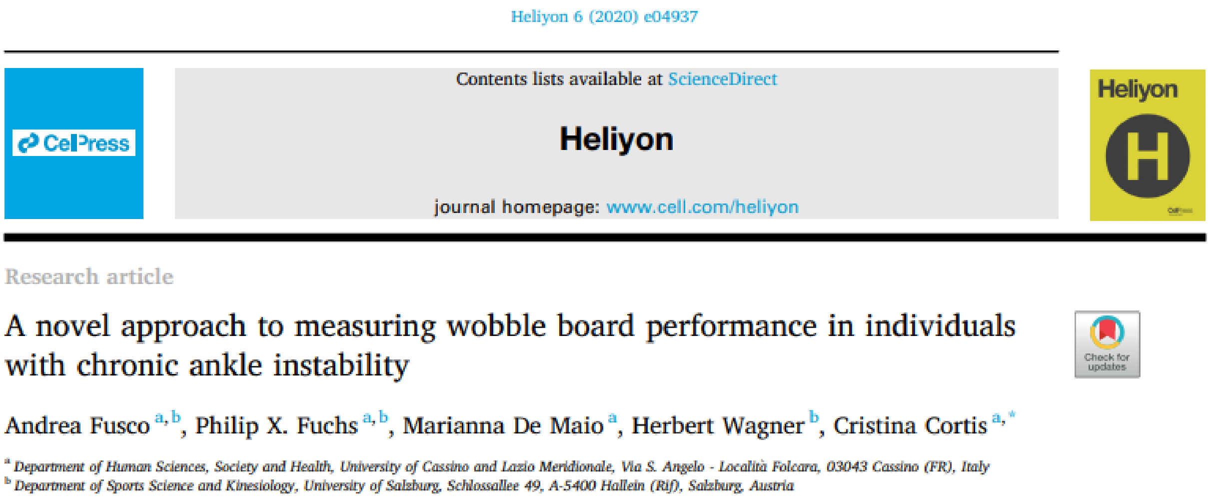
For all WB trials, the goal was to keep the MM within the TZ for as long as possible during the recording period. The boundaries of the TZ and the MM were standard for all subjects during tests. The starting limb was randomly chosen.

The GPT is considered the most appropriate test to evaluate a specific motor coordination property (manual dexterity) due its accurately and easily expose in several population as children, adults, elderly and subjects with neurological disease as PD. The GPT (Lafayette Instrument, USA; model 32025) is equipped with a square pegboard (10 cm x 10 cm) with 25 holes arranged in a 5-by 5, with random keyhole orientation and green steel pegs (diameter = 0.4 cm; model 32104) with a key along one side, located in a spherical tray above the keyholes (Figure 7).

Figure 7. Grooved Pegboard

Subjects are instructed to insert pegs one by one into the pegboard, as fast as possible, completing the rows from left to right for the right limb and from right to left for the left limb, from top to bottom (with 1-min recovery in between). Subjects are free to perform trials when they prefer. Only the dominant hand is assessed, and all individuals with PD perform the GPT two times. The GPT is placed on a table and subjects are in a comfortable sitting position, with the contralateral limb (limb not performing the test) resting on the table (Figure 8).

Figure 8. Standard Grooved Pegboard test position for Parkinson’s disease



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Research article

A novel approach to measuring wobble board performance in individuals with chronic ankle instability

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ABSTRACT

Computerized wobble boards (WB) are used to objectively assess balance in healthy and chronic ankle instability individuals. As in field setting health professionals might not own WB, objective evaluations are not always feasible. Therefore, the aim of this study was to investigate the contribution of sagittal plane joints angular- displacement and anthropometrics to predict equations to estimate WB performance by portable two- dimensional motion analysis (2D-MA) and cross-validate the developed equations in chronic ankle instability individuals. Thirty-nine healthy and twenty chronic ankle instability individuals stood on a WB in single stance position. The balance test consisted of three 30s trials per limb keeping the platform flat at 0°. Trials were video recorded, and three time-segments joints angular-displacement analyzed with 2D-MA: segment 1 (T1) including 30s data, segment 2 (T2) from second 0 to 10, segment 3 (T3) only the first 5s. Mixed regression for multilevel models was used to estimate WB performance for each time-segment and to examine limb differences for the predicted WB performance in chronic ankle instability sample. The accuracy of the equations to detect injured limbs was calculated via area under the curve for receiver operating characteristic. Ankle and knee angular- displacement parameters, body height and lower limb length were the major predictors of WB performance for the extrapolated models ($p < 0.05$; $R^2 = 0.83–0.56$). The measured WB performance and T1 model showed significant ($p < 0.05$) performance differences between the injured and uninjured limbs. Receiver operating characteristic analysis showed an asymptotic significance of 0.03 for T1 equation with area under the curve of 0.70. The proposed models provide different methods to quantify the performance and accurately detect the injured limb in individuals with unilateral chronic ankle instability, when measuring balance via WB might not befeasible. App-makers may use the equations to provide an automatic all-in-one system to monitor the performancestatus and progress.

1. Introduction

The ability to integrate sensory inputs from several receptors to determine human's movements and position in space (i.e., proprioception) plays a key role in balance control [1]. Dynamic and continuous information from the vestibular, visual and proprioceptive systems are required to provide neuromuscular adjustments essential to keep the human body center of mass within the base of support. Balance control is directly influenced by the sensorial information received and indirectly by previous injuries [2], range of motion (ROM) [3], anthropometric characteristics [4], side-general and site-specific limb effects [5], and training [6, 7]. Among several documented injuries that might influence the balance performances, ankle sprains and consequent residual symptoms such as the development of chronic ankle instability (CAI), are the most recurrent in sports, military and occupational settings, and generally in physically active people [8, 9].

Balance control is often assessed to evaluate changes after rehabilitation training intervention, deficits from previous ankle sprains and detect risk of reinjury in individuals with CAI [7, 10, 11]. Among the different methodologies, wobble boards (WBs), unstable platform generally used for proprioceptive training and rehabilitation protocols [6, 12, 13], have been recently computerized with accelerometers and connected to a computer to show reliable real-time data on balance in healthy and CAI individuals [2, 14, 15]. These systems proved to be easy

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to set up, collect and interpret data and offer the potential to monitor individuals' dynamic balance during large-scale evaluation, also in field settings. Moreover, three-dimensional (3D) motion analysis has been used to objectively quantify the WB performance and its progression [16, 17]. However, due to costs and expertise required for data collection and analysis, 3D motion analysis might not be feasible in more practical settings, and therefore, two-dimensional (2D) motion analyses [18] are preferred.

Despite the lack of precision and ability to capture rotations, 2D motion analysis could provide a practical method of evaluating sagittal plane joint displacement for assessing gross movement shift during lab- oratory and field testing, and therein risk of lower extremity injury [19]. Therefore, 2D motion analysis video systems might be used safely inclinical practice as they are portable, time and cost effective, and require little rater training [18].

Although specificity, affordability, and transportability are key factors for making the data collection accurate and precise, in some cases physical therapists, athletic trainers, practitioners and health scientists might not own a computerized WB, or simply, the device might have some technical problems. Consequently, computerized WB could not always be the most adequate tool to measuring dynamic balance, thus making the 2D motion analysis a potential solution to overcome these limitations. It could be hypothesized that 2D motion analysis system might be an accurate and precise method to estimate the computerized WB performance in healthy and CAI individuals, thus providing an alternative tool for athletic trainers and physical therapists to evaluate the dynamic balance in field setting. Therefore, the aims of this study were: (a) to investigate the contribution of sagittal plane joints (hip, knee and ankle) angular-displacement and selected anthropometrics on a computerized WB performance, (b) to predict useful equations to estimate the WB performance by using 2D motion analysis system, and (c) to cross-validate the developed WB equations in individuals with unilateral CAI.

2. Methods

2.1. Experimental approach to the problem

Computerized WBs have been recently considered useful, precise, and reliable device for balance assessment showing intraclass correlation coefficients (ICCs) ranging from 0.65 to 0.89 in healthy subjects [14] and 0.58 and 0.84 in CAI individuals [2]. However, to fulfill the lack of ac- curate surrogate methods that might substitute computerized WB during balance evaluation in clinical practice, in this study a novel approach was favored. Therefore, the concurrent use of 2D motion analysis was chosen to develop equations for estimating the WB performance because highly affordable and reliable. According to previous studies [2, 15], the one leg stance was adopted for the evaluation of the WB performance because it is a common and challenging method widely used to discriminate be- tween healthy and CAI subjects. During one experimental session a total number of six WB tests trials were performed after a familiarization period. To avoid potential fatigue, subjects were required to refrain from any moderate-to-vigorous physical activity for at least 24 h before the experimental session. All data were collected during morning sessions because diurnal patterns have been observed in dynamic balance performances [20]. Furthermore, to avoid potential effects on performances due to dehydration, participants drank water ad libitum during before and during the experimental sessions [21].

2.2. Participants

Thirty-nine healthy and twenty unilateral CAI recreationally active (engaging in at least 3 days a week of moderate-to-intense physical activity) young adults provided written informed consent to participate in the study carried out in accordance with the Declaration of Helsinki for Human Research of 1964 (last modified in 2000). The study was approved by the local Institutional Review Board (approval number: 14357.2019.06.18). The healthy participants were voluntary recruited from the local community and selected to sufficiently cover a wide range of anthropometric characteristics. They were included if self-reported: no previous injuries, fracture, or surgery of either ankle; no cerebral concussions, lower extremity injuries, vestibular and visual disorders for 3 months before testing; no ear infection, upper respiratory tract infection at the time of the study; no prior balance training. Unilateral CAI participants were selected [22] if they self-reported: at least one unilateral ankle sprain, but none within the past 6 weeks; multiple (more than 3) episodes of unilateral ankle giving way within the past 12 months; no previous fracture or surgery of either ankle; no cerebral concussions, lower extremity injuries, visual and vestibular disorders for 3 months before testing; no ear infection, upper respiratory tract infection at the time of the study; no prior balance training.

Body mass and height were measured by means of a scale with integrated stadiometer with a precision of 0.1kg and 0.1cm (Seca, model 709, Hamburg, Germany), and body mass index (BMI) calculated. Lower limb length was measured from the anterior superior iliac spine to the most distal part of the medial malleolus by using a tape measure while the subject laid in supine position. Limb dominance was also determined by asking the favorite foot to kick a ball.

2.3. Procedures

The WB performance was assessed via a computerized proprioceptive board (Balance Board WSP, Rome, Italy; 40cm diameter with a half plastic sphere of 6cm height and 20cm width; maximal tilt angle = 20°) equipped with a triaxial accelerometer (Phidget Spatial 0/0/3 Basic1041, Calgary, Canada). After a 3-minute familiarization, followed by 1-minute rest in sitting position, the participants stood barefoot on the WBin a single leg stance position, finding a comfortable and central positionwith the knee slightly bent and keeping the hands on the hips. The balance test consisted of three 30-second trials per limb with 1-minutesitting rest in between. Starting limb was randomly chosen. During the test each subject was asked to focus on the motion marker (diameter = 6mm) displayed on the monitor (1920 x 1080 resolution screen) placedat eye level 2-meter in front of them and to keep it inside the target zone (diameter = 6.5cm) as long as possible. The target zone was represented by a circle showing the 0° tilt angle measured by the triaxial accelerometer. The boundaries of the motion marker and target zone were standard for all participants during each trial. The data collected for analysis was the time (s) spent by the motion marker inside the target zone, which expresses the time the subject spent on the platform keeping it flat at 0°. Visual markers were applied by the same expert researcher to the participants' base of the fifth metatarsal, lateral malleolus, lateraljoint line of the knee, anterior superior iliac spine and acromion process.

All trials were recorded by a video camera (Sony Camcorder HDRCX290/B; Sony, Minato, Tokyo, Japan) laterally fixed at 2.30 m from the participants and 1 m above the ground. One researcher recorded the test trials, imported the videos on a motion analysis software (Dartfish Team Pro 5.5; Dartfish, Fribourg, Switzerland) and calculated hip, knee andankle angular-displacement data in the sagittal plane (Figure 1).

On each video, the same trained researcher measured joint angles from the beginning to the end of the test trial using the visual markers as references. Hip angular-displacement (Figure 1a) was measured as the angle between the acromion process and lateral joint line of the knee with the greater trochanter serving as the fulcrum. Knee angular-displacement (Figure 1b) was measured as the angle between the greater trochanter and lateral malleolus with lateral knee joint serving as the fulcrum. Ankle angular-displacement (Figure 1c) was measured as the angle between a line from the lateral knee joint and the base of the fifth metatarsal with the lateral malleolus being the fulcrum. The recorded videos of the subject's performance were analyzed at 25 frames per second. To reduce the amount of time for video analysis by athletic trainers, physical therapists and health professionals during field testing,

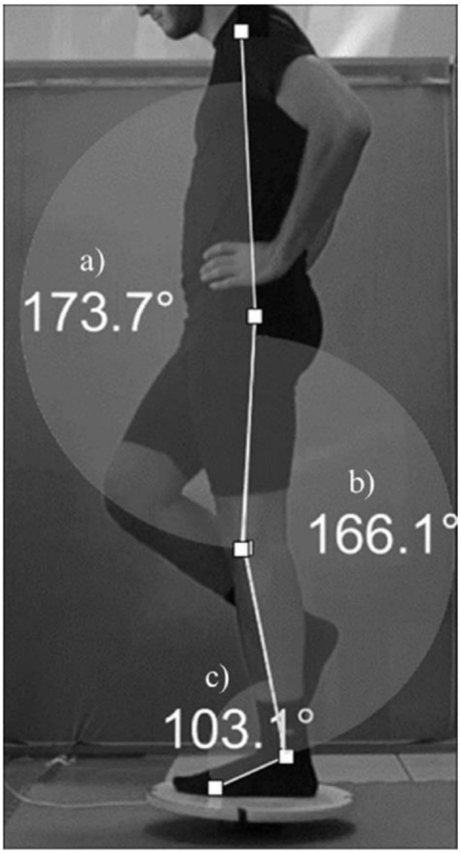

Figure 1. Example of hip (a), knee (b) and ankle (c) joint angles data in the sagittal plane.

three different time segments of the WB tests were analyzed for further statistical analysis. Segment one (T1) included 2D motion analysis data of all 30 s of the WB trial (from second 0 to second 30). Segment two (T2) included motion analysis data from second 0 to second 10. For segment three (T3) only the first 5 s of the WB trial (from second 0 to second 5) were video analyzed.

2.4. *Statistical analysis*

Data were analyzed using STATA 14 (StataCorp LP, Texas, USA). Normal distribution was verified by the Shapiro-Wilk test. Means, variance, standard deviations (SD) and range were calculated for all variables. For the WB performance, mean, variance, SD and range were calculated using all video analyzed frames as single data point for each trial and subject. Multilevel mixed regression models were created to predict equations to estimate the WB performance for each time segment video analyzed. The healthy participants were used as random effects with repeated measurements of WB performance for each subject. Bryk/Raudenbush R-squared (R^2) values and root mean squared error (RMSE) for each model were calculated. ICCs for multilevel models were also estimated. The association between measured and predicted WB performance, evaluated by calculating the Pearson's correlation coefficients (r) for each mode, was used as a measure of precision, whereas the bias- correction factor (C_b) was used as measure of accuracy. Subsequently, the Lin's concordance correlation coefficient (rho_c) was calculated as the product of r and C_b. Bland-Altman plots showing level of agreement and regression line fitting the paired differences to the pair-wise means were plotted to assess non-constant bias.

To cross validate the developed equations a subsample of twenty unilateral CAI individuals performed a single CWB trial for each leg (injured and uninjured). Multilevel model regression was performed to examine potential differences between injured and uninjured limbs for the measured and predicted WB performance in the unilateral CAI sample. Participants were considered as random effect, whereas the limbs were treated as fixed effect. The models were fitted using the residual maximum likelihood to account for the small sample. The contrast method was used to test whether the measured and predicted WB performance were identical between limb and extrapolated equations. The contrast method tests include ANOVA-style tests of the main effects used to make comparisons against the reference (measured WB performance and uninjured limb). To provide meaningful analysis for comparisons from small groups, Cohen's effect sizes (ES) were also determined. An ES less than 0.2 was considered trivial, from 0.2 to 0.5 small, greater than 0.5 to 0.8 moderate, and greater than 0.8 large. Bonferroni post-hoc tests were used for multiple-comparison adjustments across all terms. Lastly, the accuracy of the predicted WB measures in detecting injured limbs in the CAI individuals was calculated using the area under the curve (AUC) for receiver operating characteristic (ROC) curve. An academic point scale was used to classify the accuracy of the AUC for discriminating between injured and uninjured limb: fail (0.00–0.59), poor (0.60–0.69), fair (0.70–0.79), good (0.80–0.89), and excellent (0.90–1.00). The significance level was set at $P < .05$.

3. Results

Participants descriptive characteristics and joint angle average values are presented in Table 1.

Three multilevel regression models were created using the WB trial performance of the healthy participants as dependent variable (Table 2). In the first model (T1), lower limb length and ankle angle parameters (mean, variance, SD and range) were used as independent variables, with significant ($p < 0.05$) effects for all variables (ICC of 0.22). Analyzing model T1 (Table 2A), the following equation to estimate the WB performance was extrapolated:

$T1 = 36.56276 + 0.127184*\text{ankle mean } (^\circ) + 0.4046644*\text{ankle variance } (^\circ) - 4.529743*\text{ankle SD } (^\circ) - 0.2324548*\text{ankle range } (^\circ) - 0.2372182*\text{lower limb length (cm)}.$

In the second model (T2), body height, ankle angle parameters (mean, variance and SD) and knee angle SD had significant ($p < 0.05$) effects (ICC of 0.26). Accordingly, the following equation was extrapolated from the model T2 (Table 2B):

$T2 = 36.7864 + 0.1738654*\text{ankle mean } (^\circ) + 0.4629237*\text{ankle variance } (^\circ) -5.220193*\text{ankle SD } (^\circ)\ 0.5952131*\text{knee SD } (^\circ) - 0.1622368*\text{body height (cm)}.$

Finally, only the first 5 s of the WB trial (from second 0 to second 5) were video analyzed for developing the third model (T3). Lower limb length and ankle angle parameters (mean, variance and range) were significant ($p < 0.05$), with an ICC of 0.36. Therefore, the following equation to estimate the WB performance was extrapolated (Table 2C):

$T3 = 31.8308 + 0.1619749*\text{ankle mean } (^\circ)\ \text{þ}\ 0.1978885*\text{ankle variance } (^\circ) - 0.6410204*\text{ankle range } (^\circ) - 0.3059346*\text{lower limb length (cm)}.$

Bland-Altman plots and fitted regression lines with rho_c coefficients for the healthy and unilateral CAI individuals are shown in Figure 2.

The mixed effects linear regression analysis showed significant differences between injured and uninjured limb and between the measured and predicted WB performance ($F_{7,133}$ 8.80, $P < .0001$; Figure 3).

Comparisons after Bonferroni corrections showed significant differences between the injured and uninjured limb for the measured WB performance ($P < .001$, ES = 1.10) and the T1 model ($P < .012$, ES = 0.65). Furthermore, significant differences were found for the injured limb between the measured WB performance versus T2 ($P = .003$, ES = 0.64) and versus T3 ($P < .001$, ES = 0.77). The predicted models and measured WB performance did not show significant differences between the uninjured limb of the CAI sample.

The ROC curve analysis showed an asymptotic significance of 0.03 only for the T1 extrapolated equation with an AUC of 0.70 (Figure 4). The

Table 1. Descriptive characteristics and joint angle average values of the healthy and unilateral chronic ankle instability (CAI) individuals.

Descriptive characteristics	Healthy individuals			CAI individuals		
	Mean	SD	Range	Mean	SD	Range
Age (years)	23.1	2.4	10	23.5	1.5	6
Mass (kg)	64.6	10.4	34	67.3	12.9	49
Height (cm)	167.3	8.1	39	167.8	9.9	32
Lower limb length (cm)	78.8	5.3	25	78.0	6.3	23
Body mass index (kg·m^{-2})	22.9	2.8	10.2	23.9	4.1	15.4
	All individuals' healthy limbs			CAI injured limbs		
Joint angle average values*	Mean	SD	Range	Mean	SD	Range
Ankle (°)	104.1	2.1	12.5	104.6	2.8	15.4
Knee (°)	163.2	1.9	9.5	164.6	2.4	13.8
Hip (°)	170.0	2.2	11.1	170.3	3.3	16.3

* Data represent the average of all video analyzed trials using frames as single data point for each subject.

best cutoff values identified were 19.5s (sensitivity = 0.55; 1-specificity = 0.20) 20.5s (sensitivity = 0.60; 1-specificity = 0.35) and 21.5s (sensitivity = 0.75; 1-specificity = 0.45).

4. Discussion

The aims of our study were to investigate the contribution of sagittal plane joints (hip, knee and ankle) angular-displacement and selected anthropometrics on a computerized WB performance, to predict useful equations to estimate the WB performance by using a 2D motion analysis system, and to cross-validate the developed WB equations in individuals with unilateral CAI. Our main findings were that the ankle and knee angular-displacement parameters, body height and lower limb length were the major predictors of the WB performance. Furthermore, the extrapolated models accurately predicted the WB performance in healthy individuals, whereas only the T1 model was able to accurately detect WB performance differences between the injured and uninjured limb in individuals with unilateral CAI.

The first relevant finding from our study showed that the ankle, independently from the time-segment video analyzed, and knee angular-displacement played major roles on the WB performance and the accuracy of the predicting models extrapolated. This result is in line with previous studies [16, 23], which have shown that the control of standing balance during single limb tasks relies on the control of the ankle with increasing contributions of proximal joints as the balance demands become more challenging. Regarding the selected anthropometrics, only body height and lower limb length had an influence on the WB performance. Previous studies reported that body height and lower limb length should be considered during balance assessment [4, 24], while mainly focused on reaching tests for normalization purposes. To the best of our

Table 2. Mixed regression models between wobble board test performance and independent variables.

	Coef.	SE	z	P>|z|	[95% CI]	
A) Wobble board test (T1)						
Ankle mean (°)	0.127184	0.0515616	2.47	.014	0.0261252	0.2282429
Ankle variance (°)	0.4046644	0.1095888	3.69	<.001	0.1898742	0.6194546
Ankle SD (°)	-4.529743	0.8805929	-5.14	<.001	-6.255673	-2.803812
Ankle range (°)	-0.2324548	0.0925858	-2.51	.012	-0.4139197	-0.05099
Lower limb length (cm)	-0.2372182	0.0661291	-3.59	<.001	-0.3668289	-0.1076076
_cons	36.56276	8.310829	4.40	<.001	20.27384	52.85169
R²: 0.83	RMSE: 3.25				*P*: < .0001	
B) Wobble board test (T2)						
Ankle mean (°)	0.1738654	0.0593022	2.93	.003	0.0576353	0.2900955
Ankle variance (°)	0.4629237	0.1317005	3.51	<.001	0.2047955	0.7210518
Ankle SD (°)	-5.220193	0.8799794	-5.93	<.001	-6.944921	-3.495465
Knee SD (°)	0.5952131	0.2694632	2.21	.027	0.0670749	1.123351
Body height (cm)	-0.1622368	0.0516359	-3.14	.002	-0.2634413	-0.0610323
_cons	36.7864	11.83021	3.11	.002	13.59962	59.97319
R²: 0.75	RMSE: 3.62				*P*: < .0001	
C) Wobble board test (T3)						
Ankle mean (°)	0.1619749	0.0646645	2.50	.012	0.0352349	0.288715
Ankle variance (°)	0.1978885	0.099032	2.00	.046	0.0037894	0.3919877
Ankle range (°)	-0.6410204	0.1708659	-3.75	<.001	-0.9759114	-0.3061294
Lower limb length (cm)	-0.3059346	0.0961308	-3.18	.001	-0.4943475	-0.1175217
_cons	31.8308	10.92265	2.91	.004	10.4228	53.23881
R²: 0.56	RMSE: 3.74				*P*: < .0001	

T1 = Time-segment one; T2 = Time-segment two; T3 = Time segment three; SD = Standard deviation; _cons = Intercept; coef. = Coefficient; SE = Standard errors; CI = Confidence Interval; R2 = Bryk/Raudenbush R-squared; RMSE = Root mean squared error.

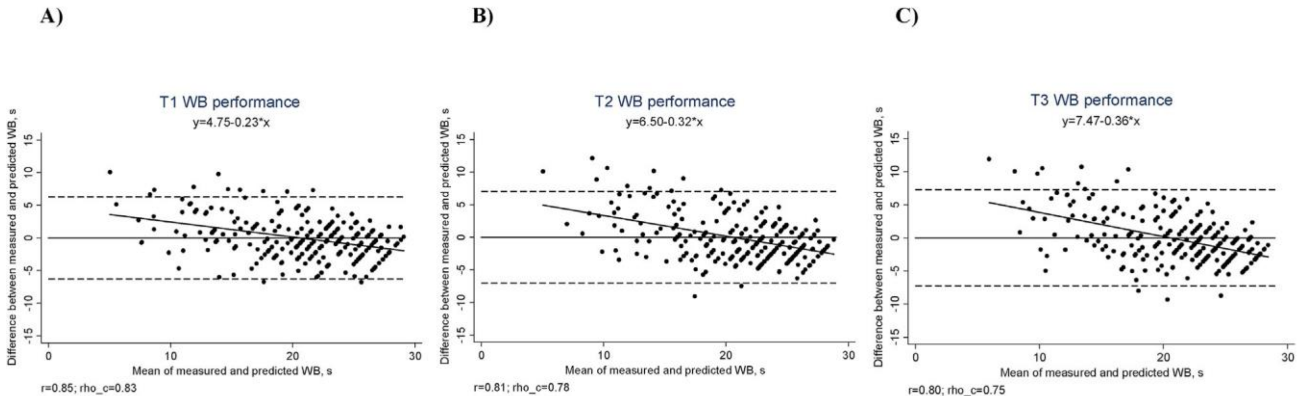

Figure 2. Bland-Altman Plots for A) T1, B) T2, and C) T3 extrapolated wobble board performance models. Difference between predicted and measured wobble board performance is plotted against the mean of the respective measurements. Horizontal black line indicates the average of the differences, whereas the dashed lines show the upper and lower 95% limits of agreement. Black fitted linear regression line is also displayed. T1 = Time-segment one; T2 = Time-segment two; T3 = Time segment three; WB = Wobble board; r = Pearson's correlation coefficient; rho_c = Lin's concordance correlation coefficient.

knowledge, there are no studies that investigated the direct impact of lower limb length on balance performances assessed on computerized WB. However, our results regarding body height are in line with Greve et al. [25], which demonstrated that body height had moderate correlation with balance performances evaluated on a Biodex balance system. Therefore, our findings confirm what has been previously reported by Berger et al. [26] and Alonso et al. [27], which stated that ankle dis-placements increased with body height. This is further explained by the “inverted pendulum” theory [28]. According to the theory, during up- right position the human body can be compared to an inverted pendulum system rotating around the ankle joint, thus the anthropometrics, especially body height, could be affected by the total load of movements occurring at the top of the inverted pendulum [29]. Therefore, an in- crease of body height, could lead to an increased ankle torque essential to keep postural balance particularly during single leg stance on unstable platform [25, 26, 27].

Three different time-segments were video analyzed by the same trained researcher in order to develop useful equations for predicting the WB performance. The R^2 statistics, the % variation in measured WB explained by the model, ranged from 56% (T3) to 83% (T1), with an absolute difference between the predicted and measured WB performance ranging from 3.25-3.74 s. Alongside the video analysis of the overall WB performance (T1), for practical reasons we choose, a priori, to develop equations for the first 10 s (T2) and 5 s (T3). Clinically, the ability to quickly reproduce reliable surrogate measurements is crucial, especially during large scale evaluations. Therefore, to estimate the adequacy of the models, the ICCs for multilevel models were calculated. Numerical value of this index, ranging from 0.22 to 0.36, indicate that multilevel modeling is a suitable model to analyze the existing data and multilevel analysis can better present results compared to simple regression [30]. For example, the T2 ICC of 0.26 would suggest that 26% of the outcome variability depends on differences among individuals, whereas the remaining 74% depends on differences between the measurements made in the same subject.

Despite the measures of precision and accuracy were strong, the developed equations were slightly biased as we used a mixed model (with participants as random effect) method [31, 32]. In fact, visual examination of the Bland-Altman plots suggests that the differences between the measured and predicted WB performance were not constant, with the predicted models increasingly overestimating the measured WB performance [33]. By using the difference in WB

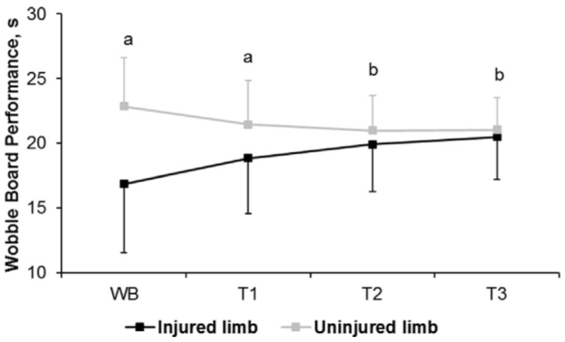

Figure 3. Means and standard deviations of meaured (WB) and predicted (T1 = 30s; T2 = 10s; T3 = 5s) wobble board performance across injured and uninjured limbs in the chronic ankle instability sample. a: significantly ($P < .05$) different from the uninjured limb; b: significantly ($P < .05$) different from the measured (WB) wobble board performance.

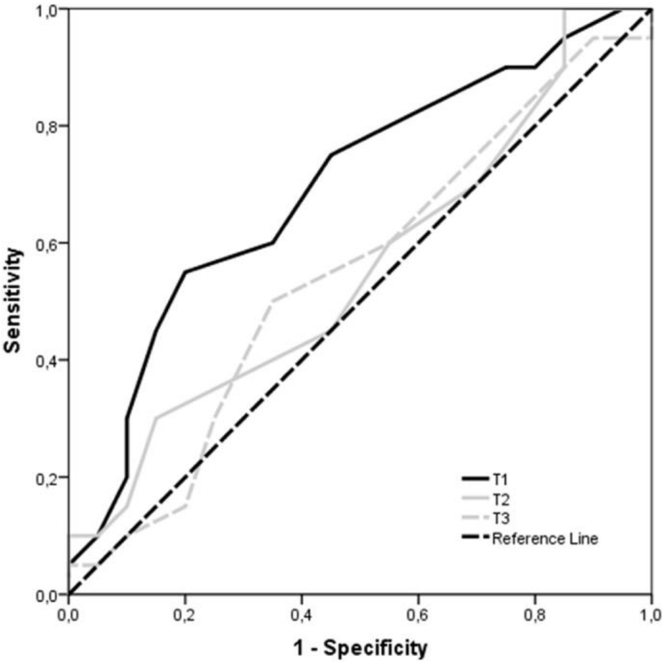

Figure 4. Receiver operating characteristic (ROC) curve for the extrapolated wobble board performance models (T1 = solid black; T2 = solid grey; T3 = dotted grey) indicating sensitivity and 1− specificity tradeoff are shown relative to the reference line (dotted black), which indicates that a test performed no better than random.

performance as a dependent outcome variable and the mean between the two methods of measurements as an independent predictor in a linear regression for each model, regression line with slope ranging from -0.23 to -0.36 were obtained. For example, the predicted T2 equation, on average, overestimated the measured WB performance by 0.32 s for each second increase in the measured WB performance. A biphasic trend was also evident in all Bland-Altman plots. Therefore, according to the regression line, the predicted values on the y-axis were positive at the lowest mean value of the two measurements onthe x-axis, and the values on the y-axis were negative at the largest difference between the two methods. This suggests that the extrapolated models overestimate the measured WB performance when the magnitude of the measurement is large, but on the other hand, underestimate when the magnitude is small [34].

The consistency and precision of the extrapolated models as indirect methods for WB assessment in healthy limbs is clearly supported by the results. In fact, no significant differences were demonstrated between the measured WB performance and extrapolated models for the uninjured limb of the unilateral CAI sample. On the other hand, the T2 and T3models were unable to successfully and accurately detect limb differences in individuals with unilateral CAI. Interestingly, the cross- validation of the developed equations in individuals with unilateral CAI showed that the T1 extrapolated model was able to successfully and accurately detect limb differences in individuals with unilateral CAI, alongside the measured computerized WB outcome, which have shownto be in line with previous studies [2, 15]. The accuracy of the T1 extrapolated equation is further strengthen by the significant AUC of 0.70, which is considered to be fair. The best cutoff values ranged from 19.5s to 21.5s, which are similar to the one reported in a previous studyof 18.5s [2]. Therefore, based on the cutoff value of 20.5s, the 60% of the injured limb (true positive) would be correctly classified as injured, whereas the 35% of the uninjured limb would be incorrectly identified asinjured (false positive).

Despite the meaningful results of our investigation, some limits need to be acknowledged. Our sample was limited to healthy young adults and participants with unilateral CAI, and therefore other populations, such as older adults or other clinical populations, could have different predictors and results for the WB performance. Secondly, as feedback can enhance neuromuscular control, it is possible that visual feedback provided when showing real time performance, could have affected the influence of anthropometrics and joints angular-displacement parameters on the WB performance [35]. Therefore, it should be determined whether the predicted models would have similar precision and accuracy with or withoutvisual feedback. As this study analyzed only the sagittal plane, futureresearches should investigate other planes of motion as well as other joints. Lastly, the analysis of human movement using 3D or 2D motion analysis system is prone to instrument and observer errors, such as the identification of anatomical landmarks. Therefore, future studies should investigate the interrater reliability and consistency of such approach, as well as the cross-validation of the predicted models with other clinical populations.

5. Conclusions

Ankle and knee angular-displacement parameters, body height and lower limb length were the major predictors of the WB performance and played major roles on the accuracy of the extrapolated models. The equations may provide different methods to quantify the WB performance and accurately detect the injured limb in individuals with unilateral CAI, when measuring balance via computerized WB might not be feasible. Therefore, this could help physical therapists, athletic trainers, practitioners and health scientist to quickly assess the WB performance. Furthermore, app makers may use the equations to provide an automatic all-in-one system to monitor and document the WB performance status and progress.

Declarations

Author contribution statement

A. Fusco: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

C. Cortis: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

M. De Maio: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

P.X. Fuchs: Analyzed and interpreted the data; Wrote the paper.

H. Wagner: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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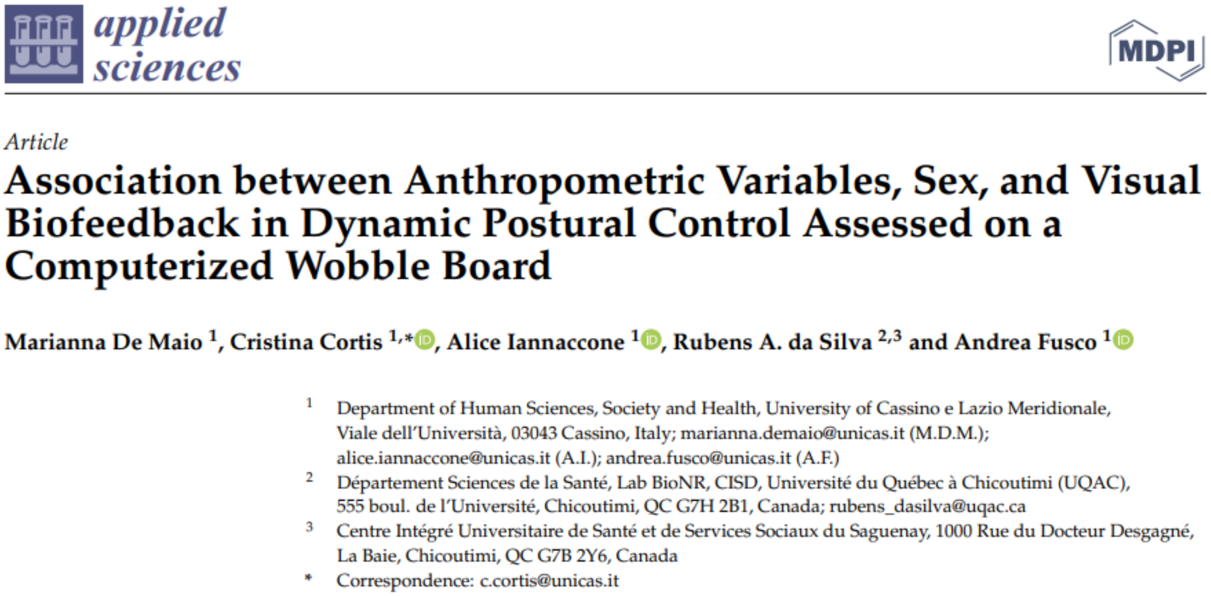

Article

Association between Anthropometric Variables, Sex, and Visual Biofeedback in Dynamic Postural Control Assessed on a Computerized Wobble Board

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Abstract: Anthropometrics and sex influence balance performances, and visual information can change anthropometrics' relation and the postural sway. Therefore, the aim of the present study was to evaluate the effect of anthropometric characteristics, sex, and visual biofeedback and/or their interaction on a computerized wobble board. Twenty-seven (14 females, 13 males) young adults performed three 30-s double leg stance trials on a wobble board during two conditions: with visual and without visual biofeedback. Visual biofeedback improved (p = 0.010) balance on a wobble board with respect to the condition without visual biofeedback. Regardless of sex, no differences between conditions were found (p = 0.088). When investigating the effect of anthropometrics variables, sex, and their interactions on conditions, a significant main effect of the lower limb/height ratio, sex, and their interaction on the condition without visual biofeedback was found (p = 0.0008; R^2 = 0.57). For the visual biofeedback condition, significant effects for sex and body mass (p = 0.0012; R^2 = 0.43) and sex and whole-body moment of inertia (p = 0.0030; R^2 = 0.39) were found. Results from the present study showed (1) visual biofeedback improved wobble board balance performance; (2) a significant main effect of lower limb/height ratio, sex, and their interaction on the wobble board performances without visual biofeedback emerged; (3) significant effects were found for sex and body mass and sex and moment of inertia in the visual biofeedback condition. Findings from the present study could have an impact on training and evaluations protocols, especially when several populations such as children, athletes, older adults and people with balance disorders are involved.

Keywords: anthropometry; sex; biofeedback; somatosensory information; postural control; young adults; wobble board

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1. Introduction

Balance is defined as the ability to maintain or make adjustment in order to keep the body's center of mass (CoM) over the base of support (BoS) through an integrative use of somatosensory, visual, and vestibular systems [1,2]. According to its definition, balance can be divided into static balance, which is the ability to keep the BoS through minimum motion, and dynamic balance, as the ability to maintain balance while the CoM is projected outside the BoS [3].

Several factors, such as anthropometrics, sex, and feedbacks play a key role in postural control. Studies [4–7] focusing on the anthropometric variables have shown that bodymass [4,8], height [6,9] and lower limb length [9] are directly related to postural control over the lifespan. In fact, body mass negatively influences the postural control of adolescents [10], young adults [9,11], and the elderly [12]. Similarly, body height and lower limb length have been identified as the most influencing anthropometric variables in young adults [9]. On the contrary, although the influence of sex on postural control is well known, findings are not conclusive, with some studies showing better balance in women [13], and others in men [14], or showing no differences between sex [15].

Postural control can also be influenced by cognitive processes such as the attentional focus, which can be driven by feedback such as visual biofeedback (VBF) [16,17] and acoustic biofeedback [18], with VBF more effective and accurate when compared to other sensory modalities. VBF can be presented by providing subjects with additional artificial visual information about body movement designed to augment the natural information and facilitate the adoption of appropriate strategies to keep postural control as steady as possible [17,19]. Therefore, when designing a VBF system, the methodology applied plays a crucial role. In the literature, some studies used a direct visualization of real-time location of the subject's center of pressure (CoP) [20–22], while others displayed the subject's relative lateral (left vs. right) weight distribution [23–25]. In some cases, a numerical representation of the percentage of weight distribution between the left and right feet has also been used [20,26]. Regardless of the modality, these studies showed that VBF has a positive influence on balance and that even small changes in feedbacks can make a difference in balance performances, probably due to the enhanced neuromuscular control [16].

In clinical and field settings, the assessment of balance can provide accurate and sophisticated information regarding the efficiency of the neuromuscular system. Several postural control assessments have been used to evaluate dynamic balance. Force plates [27] and functional tests [28,29] are commonly used to evaluate balance performances due to their accuracy, validity, and reliability. However, because of the multifaceted features of the postural control tests, by clearly reflecting the complexity of this ability, new simple approaches [30,31] are needed to accurately evaluate dynamic postural control. In particular, during large-scale evaluations, practical, inexpensive, administrable, and accurate tools are preferable. In this context, computerized wobble boards (WBs) have been suggested as reliable and simple tool to evaluate dynamic balance in healthy young subjects in field and laboratory settings [31–33]. Unstable platforms, such as WBs, are the most used tools to train human balance, showing their effectiveness in improving postural control among different populations [34].

Although the influence of anthropometrics, sex, and VBF on human balance is well documented, focusing on the effect of the above-mentioned factors and/or their interaction on computerized WB could provide useful information to adapt and tailor individualized balance training protocols. Therefore, the aim of this study is to evaluate the effect of anthropometric characteristics, sex, and VBF during dynamic balance performance assessed on a computerized WB in young healthy adults.

2. Materials and Methods

2.1. Subjects and Procedures

The Institutional Review Board of the Department of Human Sciences, Society, and Health of the University of Cassino and Lazio Meridionale approved this study (approval No.: 14357; date: 18 June 2019), designed to evaluate the effects of anthropometric characteristics, sex, and VBF on balance performances in healthy young adults. Prior the evaluation, twenty-seven subjects (14 females, 13 males) were voluntarily selected among the students' population. They were fully informed about the procedures and the aim of the study, and subsequently their informed consent was provided. Subjects were excluded if they reported any pre-existing condition such as neurological condition, musculoskeletal injury of the back or lower extremities, or any other disorder that could influence their balance ability.

Before starting the testing session, subjects' characteristics were assessed. Body mass and height were measured by means of a scale with an integrated stadiometer with a precision of 0.1 kg and 0.1 cm (Seca, model 709, Vogel & Halke, Hamburg, Germany), and body mass index was calculated. In addition, whole-body moment of inertia (MI), an inertial quantity measurement of the human body essential for quantitative analysis of human motion, was collected. Subjects' MI on the frontal axis through the center of masswas computed using the following Equation (1) [35]:

$$\mathrm{MI} = (3.44 \cdot \mathrm{HT}^2) + (0.144 \cdot \mathrm{M}) - 8.04 \quad (1)$$

where HT (m) represents height and M (kg) body mass. Lower limb length was also measured from the anterior superior iliac spine to the most distal part of the medial malleolus by using a tape measure while the subject laid in supine position. Subsequently, the relative lower limb length, which defines the proportion of total stature that is comprised by thelower limbs, was also computed.

2.2. Wobble Board Test

Computerized Balance Board WSP (Well Sport Project, G.S.J. Services S.r.l., Rome, Italy) is a proprioceptive platform; we used the WB model, incorporating a triaxial accelerometer (Phidget Spatial 0/0/3 Basic 1041, Phidgets Inc. 2016, Calgary, AB, Canada). The platform is composed by a circular surface (diameter 40 cm, height 2 cm) and placed on a plastic material semispherical support (diameter 12 cm, height 6 cm). The WB model is connected via USB cable, with a sampling frequency of 200 Hz. The WB tilt (maximal tilt angle = 20°) angle data is then transmitted to a customized software displaying real time balance performance on a monitor (resolution = 1920 1080×) through a motion marker (MM, diameter = 6 mm). The software user interface showed the MM, represented by a yellow circle, a Target Zone (TZ, diameter = 6.5 cm) displayed by a red circle which represented the stability area (0° tilt angle), and a countdown of the trial. The boundaries of the TZ and the MM were the same for all subjects during experimental sessions.

After a detailed explanation of the testing procedures, with a short demonstration and verbal support, subjects were asked to stand barefoot on the WB, which was placed directly on the floor, with a comfortable double leg stance, keeping their hands on their hips and instructed to keep the board flat (0° tilt) and as still as possible for as long as possible within a recording period of 30 s.

The test session consisted of a 3-min free practice on the WB followed by three 30-s double leg stance trials and 1-min sitting recovery in between. Subjects were asked to perform two conditions: (1) with VBF, where subjects were asked to keep visual focus on the MM showed on the display and try to keep it inside the TZ as long as they could within 30 s; and (2) without Visual Biofeedback (NVBF), looking at a fixed point on a black board, where subjects were asked to keep visual focus on a marking in front of them and instructed to maintain the WB as flat and still as possible for as long as possible within the recording period of 30 s. During the VBF and NVBF condition, the screen or the black board were positioned 2 m far in front of the WB while standing on it. The order of conditionswas randomly assigned.

2.3. Statistical Analysis

Normal distribution was verified by the Shapiro-Wilk test, and means and standard deviations (SD) were calculated for all variables. Data were analyzed using STATA 15 (StataCorp LP, College Station, TX, USA). Statistical significance was set at $p < 0.05$. Firstly, a repeated measures mixed model was applied to evaluate the possible differences in balance performance between the VBF and NVBF conditions in relation to sex. Participants were considered as random effect, whereas conditions (VBF and NVBF) and sex were treated as fixed effect. The models were fitted using the residual maximum likelihood to account for the small sample. Subsequently, the trend over trials for each condition in relation to sex was checked by using orthogonal polynomial contrasts. Finally, the main effect of sex and its interactions with selected anthropometric characteristics for each condition was investigated using mixed linear regression models. Bryk/Raudenbush R-squared (R^2) values were calculated for each model.

3. Results

Subject's characteristics are represented in Table 1.

Table 1. Means and standard deviations of the subjects' characteristics.

Characteristics	Female (*n* = 14)	Male (*n* = 13)	Total (*n* = 27)
Age (years)	24.0 ± 1.9	26.5 ± 3.3	25.3 ± 1.0
Lower limb length (cm)	74.5 ± 3.6	85.7 ± 3.8	80.1 ± 0.1
Body mass (kg)	53.3 ± 4.4	76.0 ± 6.9	64.7 ± 1.7
Height (cm)	158.9 ± 5.6	176.5 ± 5.3	167.7 ± 0.2

BMI = body mass index.

The repeated measures mixed model analysis showed a significant main effect for the VBF condition (*p* = 0.010; 95% Confidence Intervals (CI) = 0.74−–5.45) (Figure 1). No significant differences were found between sexes (*p* = 0.088; 95% CI = −5.62–0.39).

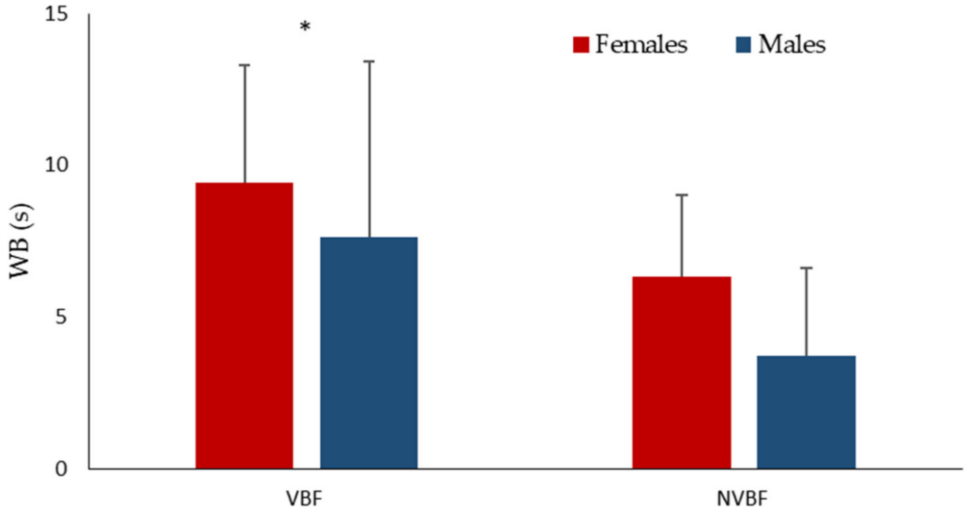

Figure 1. Means and standard deviations of wobble board balance performances (WB) for visual biofeedback (VBF) and no visual biofeedback (NVBF) in both sexes. * significantly different from the no visual biofeedback (NVBF) in male and female.

As there were no sex differences between conditions, the trend over trials for each condition was checked by aggregating both sexes. The orthogonal polynomial contrasts analysis showed a significant linear trend ($p \leq 0.0001$; 95% CI = 1.16–3.13) only for the VBF condition with an estimated linear slope 2.15 s (Figure 2).

When investigating the effect of selected anthropometrics, sex, and their interactions on both conditions, the mixed linear regression analysis showed a significant main effect of the lower limb/height ratio (HTR), sex, and their interaction on the NVBF performance(*p* = 0.0008; R^2 = 0.57) (Table 2). For VBF, two models were developed, and significant effects were found for sex and body mass (Table 3; *p* = 0.0012; R^2 = 0.43) and sex and MI (Table 4; *p* = 0.0030; R^2 = 0.39). Interactions and main effects are graphically represented in Figures 3–5.

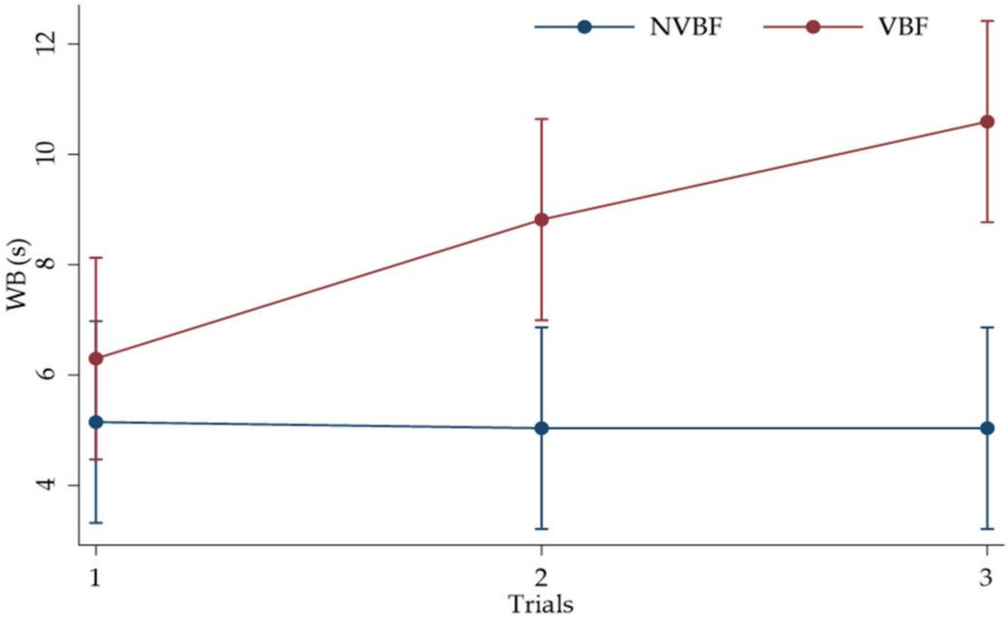

Figure 2. Wobble board (WB) performance trend over trials for the visual biofeedback (VBF) and no visual biofeedback (NVBF) conditions.

Table 2. Mixed regression model between wobble board test performance (WB), sex, the lower limb/height ratio (HTR) and their interaction in the no visual biofeedback (NVBF) condition.

WB	Coef.	Std. Err.	Z	$p > \|z\|$	95% Conf.	Interval
Sex (F = 0; M = 1)	—102.8941	39.55309	−2.60	0.009	−180.4167	–25.37143
HTR	—156.8785	57.26048	−2.74	0.006	−269.1069	–44.65001
Sex x HTR	211.9493	82.81277	2.56	0.010	49.63925	374.2593
Cons	79.88784	26.85465	2.97	0.003	27.2537	132.522

Coef. = coefficient; Std. Err. = standard errors; Conf. = confidence; F = female; M = male; HTR = lower limb/height ratio; Cons. = intercept.

Table 3. Mixed regression model between wobble board test performance (WB), sex and body mass during the visual biofeedback (VBF) condition.

WB	Coef.	Std. Err.	Z	$p > \|z\|$	95% Conf.	Interval
Sex (F = 0; M = 1)	8.899321	3.434602	2.59	0.010	2.167625	15.63102
Body mass (kg)	—0.472319	0.136382	−3.46	0.001	−0.7396228	−0.2050153
Cons	34.62342	7.349873	4.71	0.000	20.21793	49.02891

Coef. = coefficient; Std. Err. = standard errors; Conf. = confidence; F = female; M = male; Cons. = intercept.

Table 4. Mixed regression model between wobble board test performance (WB), sex and whole-body moment of inertia (MI) during the visual biofeedback (VBF) condition.

WB	Coef.	Std. Err.	Z	$p > \|z\|$	95% Conf.	Interval
Sex (F = 0; M = 1)	8.915472	3.681939	2.42	0.015	1.699004	16.13194
MI (kg/m^2)	—2.024108	0.6322252	−3.20	0.001	−3.263246	–0.7849689
Cons	26.29451	5.375726	4.89	0.000	15.75828	36.83074

Coef. = coefficient; Std. Err. = standard errors; Conf. = confidence; F = female; M = male; MI = whole-body moment of inertia; Cons. = intercept.

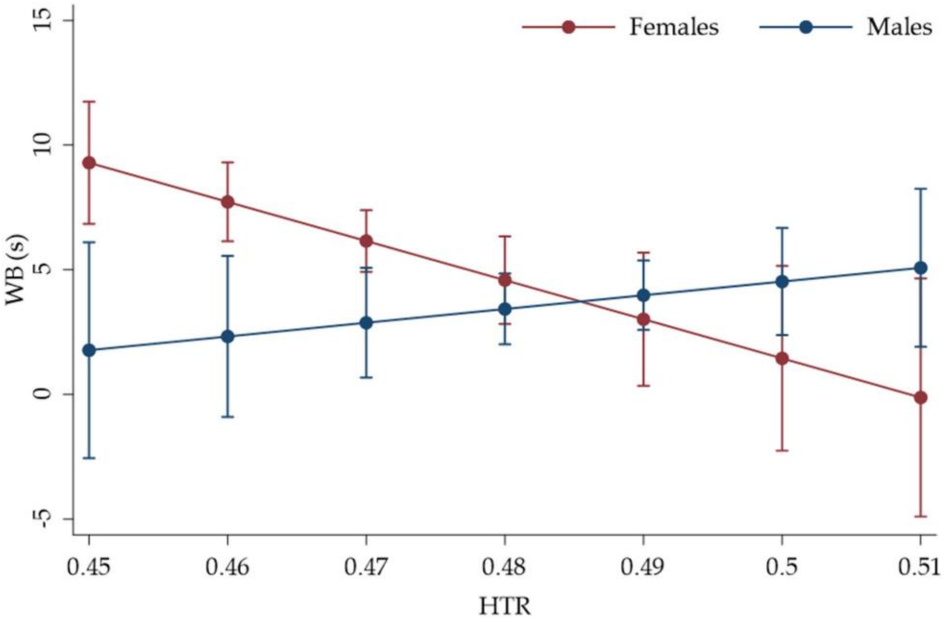

Figure 3. The interaction of lower limb/height ratio (HTR) and sex in the no visual biofeedback (NVBF) condition.

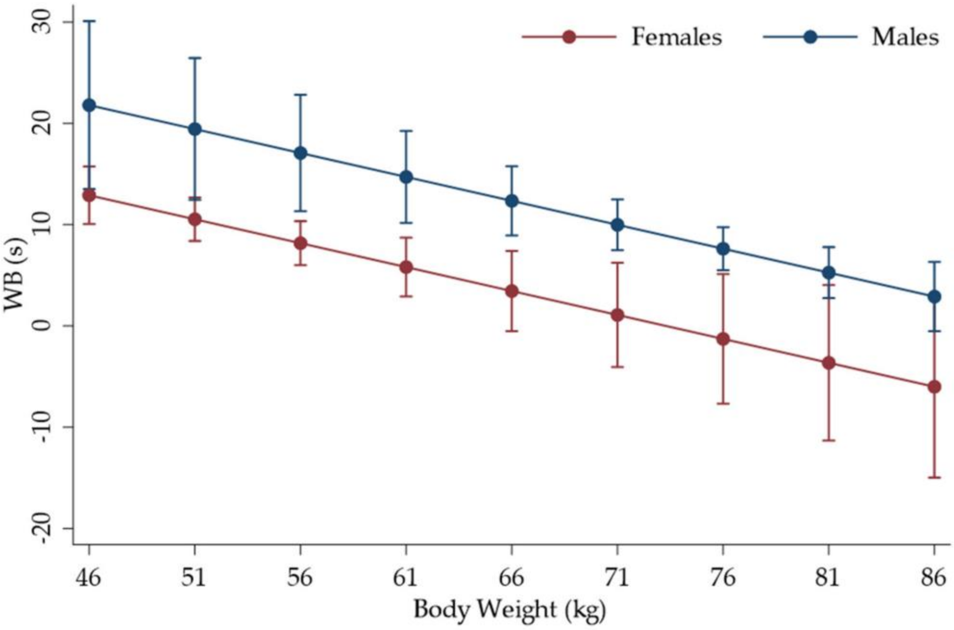

Figure 4. Main effect of body mass on the wobble board performance (WB) during the visual biofeedback (VBF) condition in relation to sex.

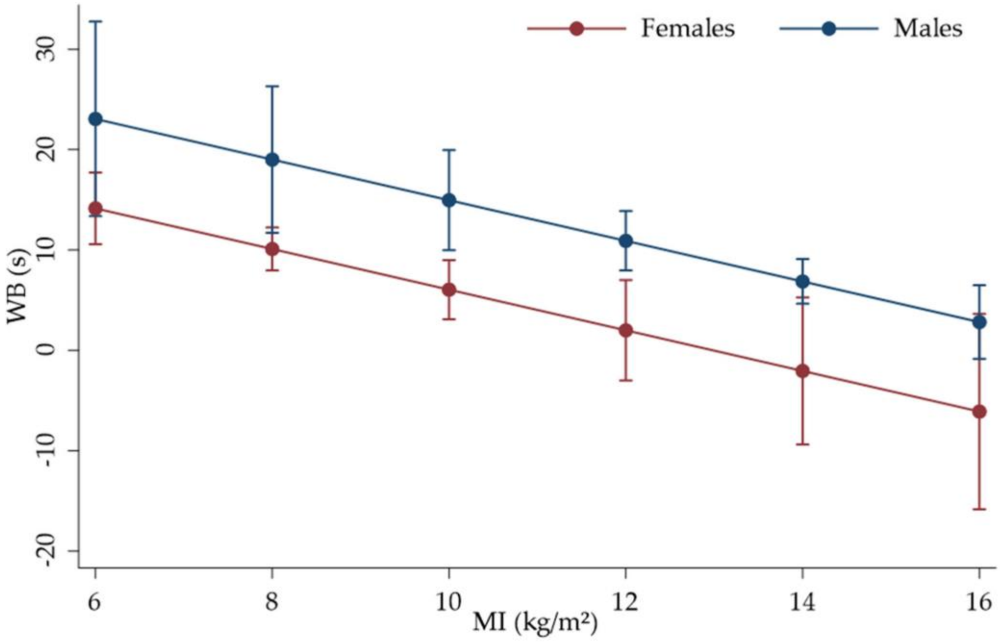

Figure 5. Main effect of whole-body moment of inertia (MI) on the wobble board performance (WB) during the visual biofeedback (VBF) condition in relation to sex.

4. Discussion

The purpose of this study was to evaluate the effect of anthropometric characteristics, sex, VBF, and their interaction on computerized WB during dynamic balance performance in healthy young adults.

Biofeedback has been used for many years in rehabilitative and preventive training protocols among different populations, such as healthy [19,36] or pathological populations [37–39]. However, VBF, due to its immediate, continuous, correct, and accurate information, represents the most effective modality compared to others sensors during dynamic balance performances [40]. To confirm this, evidence showed better balance in judo athletes [41], young karatekas [42], healthy subjects [40,43], young adults [44], and elderly people [45] when performing VBF compared to NVBF. Although previous studiesare in line with the present findings, comparisons are difficult because of the different VBF and balance outcome used. However, Cawsey and colleagues [46] showed that an increase in dependence on augmented sensory information for the control of standing posture influences the somatosensory input conditions of the foot and ankle, confirming the significant differences during the VBF condition with respect to NVBF. It is well known that standing on an unstable platform results in changes in sensory biofeedback and subjects increasing their reliance on visual information. Therefore, the postural control could be more efficient in the VBF condition when standing on an unstable platform. Another possible explanation could be related to the VBF methodology applied. In the present study, real-time VBF showing a MM and a TZ portrayed by a red circle was used. For this reason, such VBF characteristics could have improved the WB performance by influencing the subjects' postural strategies and facilitating accuracy and goal directedness of postural dynamic control. Therefore, based on the present results, VBF condition should be taken into consideration during WB balance assessment and neuromuscular training.

Literature also suggests that visual information changes the relationship between anthropometrics and the postural sway [9]. In fact, in a previous study [9] a greater correlationbetween postural sway and body mass was found when the balance test was performed with eyes opened. Similarly, in the present study, a significant relationship between bodymass and balance performance was found in the VFB (in both sexes) condition. On the contrary, in other studies, postural sway increased in NVBF conditions such as balance tests with eyes closed [47,48]. This is probably due to the difference in the NVBF modality.

In fact, although the eyes closed condition might be included in the NVBF category, there might be a difference in terms of difficulty between having a visual cue with eyes open (a mark on a black board) and the eyes closed with no visual orientation.

In addition, in this study, a significant relationship between MI during the VBF condition in males and females was also found. MI is a mechanical parameter of the human body, usually used in studies on balance and posture, in correlation with other parameters, such as body mass and lower limb strength [35]. An explanation about this result might be found in the test execution. In fact, although the test protocol was standardized in terms of execution with clear directions, such as standing barefoot on the WB with a comfortable double leg stance, keeping hands on the hips and the board flat at 0° tilt, no further indications were provided about the trunk control. It might have happened that during the test execution the subjects leaned forward or backward with their trunks in order to focus on the screen to keep their balance, and as MI estimates the subjects' whole body MI on the frontal axis through the centre of mass, this further centre of mass displacement might have influenced the performance during the VBF condition [7,49].

Commonly, limbs' length, especially upper limb length, has shown a positive correlation in postural sway in both eyes opened and closed condition in females [50]. This positive relationship has been mainly attributed to reaching tests, where longer limbs might favour the subjects during the tests. However, in the present study, a significant negative relationship between HTR and postural control in males and females during theNVBF condition was found. Usually, taller individuals, more evident in males, tend to have longer lower limbs, and this condition is often associated with a greater distance between the centre of mass and BoS, resulting in a higher postural sway [51]. However, in the present study, an interaction between HTR and sex during the NVBF was found. In particular, at higher HTR values, men increased their dynamic balance performance, while women decreased it. Direct comparisons of these results are difficult as no studies have compared the effect of HTR and sex on WB performances. However, Alonso et al. [50] focused their attention exclusively on lower limbs length, and in contrast with this study, showed a moderate path sway in males when eyes were closed. The authors hypothesized that the sex differences found during performances when eyes were opened and closed were due to greater anthropometric variables, lower flexibility, and slower neurophysiologic processing of inferences in men. Nevertheless, focusing on these findings, we cannotconfirm these assumptions.

In the present study, when comparing the VBF test trials, learning effect was evident regardless of sex. Few studies [52,53] focused their attention on learning effect. A previous study [52] showed that one trial for each test task created insufficient self-confidence, allowing individuals not to feel confident with the tasks. For increasing sufficient self-confidence, a good strategy could be to increase the trials' number. In fact, in the present study, individuals performed three dynamic trials on the WB. Similarly, in Wrisley et al. [53], young adults performed three trials for each test session, showing significant learning effect during both the eyes opened and eyes closed conditions. In the present study, during VBF condition, both males and females reported the same learning effect. On the other hand, during NVBF condition, no learning effect was found for both sexes. Evidence [54,55] has shown that with repeated balance activities, performance improves, especially during complex tasks such as standing on unstable platform or when visual information is suppressed. However, due the different methodologies used, comparison was difficult. It also could be interesting to evaluate if the learning effect would be as evident among several populations, such as subjects with visual or proprioceptive deficits.

Several limitations need to be acknowledged for this study. The sample was limited to healthy young adults. Other populations such as elderly people, athletes, or subjects with chronic diseases should be evaluated to explore possible differences. In addition, it could be possible that other VBF strategies might have a different influence on WB performances. Finally, since only a few studies using WB as an assessment tool are available in the literature, the results of this study cannot be compared with other studies.

5. Conclusions

Findings from this study highlighted that VBF may improve WB balance performance with respect to the NVBF condition in healthy young adults. Regarding the anthropometrics variables, results showed a significant main effect of HTR, sex, and their interaction on the NVBF WB performance. For the VBF condition, instead, significant effects were found for sex and body mass and sex and MI. In addition, results from the present study couldhave an impact on training and evaluations protocols, especially when several populations such as children, athletes, older adults and people with balance disorders are involved. In fact, specific balance exercises such as the monopodalic stance, the double leg stance, the tandem stance on foam, and walking on unstable surfaces with (to ensure the safety of individuals) or without support during eyes opened and closed conditions could improve neuromuscular control. Lastly, the affordability and transportability of WBs are key factors during filed evaluations, making data collection on balance performances feasible for health scientists and/or coaches looking for inexpensive, portable, reliable, and valid assessment tools. However, further research should assess different populations to evaluate the effectof anthropometric characteristics, sex, VBF and NVBF, and their interaction on WB.

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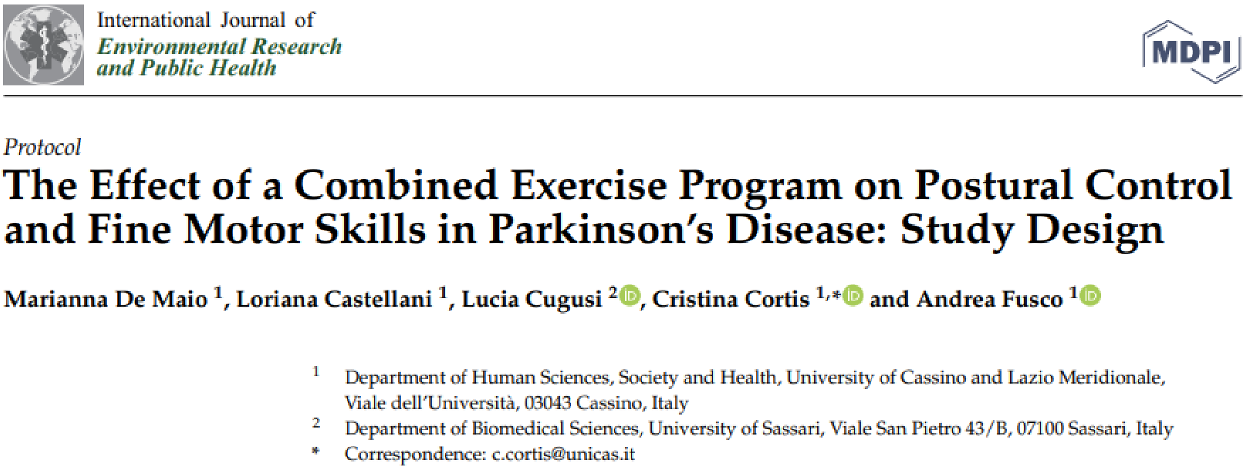

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Protocol

The Effect of a Combined Exercise Program on Postural Control and Fine Motor Skills in Parkinson's Disease: Study Design

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Abstract: Parkinson’s disease (PD) is a progressive and neurodegenerative disorder defined by physical symptoms such as hand disability and postural instability. To counteract the detrimental effects of PD, physical activity programs showed improvements in overall aspects of physical functioning. Therefore, this protocol will aim to evaluate the effect a of postural and fine motor skills training program in older adults with PD. PD individuals, with mild to moderate stage PD, aged between 65 to 80 years, will be voluntary selected from the Nursing Home Residences and Rehabilitation Centers. Subsequently, they will be randomly assigned to intervention group (PD) to receive a combined training program (postural control and fine motor skills exercises) or to the Control group (CON) to receive a stretching program. Before (PRE) and after (POST) a 12-week program both groups will perform wobble board (WB) and grooved pegboard (GPT) tests. Different performances between groups will be expected: (1) no significant differences between PD and CON group for WB and GPT test values before the beginning of the training intervention (PRE); (2) significantly better WB and GPT test values in PD subjects after the training intervention (POST) when compared to the base values (PRE); and (3) no significant differences in WB and GPT test values in CON subjects after the training intervention (POST) when compared to the base values (PRE). The findings of the present study protocol could be used for future studies investigating clinical populations, such as PD, and the effects of different rehabilitative interventions aiming to improve postural control and fine motor skills performances assessed by WB and GPT tests.

Keywords: Parkinson’s disease; training program; fine motor skills; postural control; grooved pegboard; wobble board

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1. Introduction

Aging is defined as a natural, continuous and irreversible process that leads to both cognitive and physical decline, characterized by a reduction in coordination, loss of balance and the onset of several diseases [1], such as Parkinson disease (PD). PD is a slow-progression neurodegenerative disease with a high incidence in aged people, affecting 1% to 2% (1.1 million) of the older population above 65 years of age [2,3]. However, definitive conclusions about the etiology of PD have not been reached. It is generally considered to be a consequence of the simultaneous action of toxic and genetic agents (oxidative stress, mitochondrial abnormalities, excitotoxicity, inflammatory factors, environmental neurotoxins, genetic factors and brain aging) able to degenerate the actions of the dopamine neuron in individuals [4,5]. PD is mainly characterized by non-motor and motor symptoms. Non- motor symptoms, such as impairments in memory, communication, visuo-spatial skills, emotional difficulties, anxiety and depression, compromise cognitive abilities, emotionality and personality. Motor impairments, such as tremor disorder and postural changes, result in an increase of rate of falls and dysfunction in ambulation and the fine motor skills system [5,6], thus negatively affecting the individual’s self-care activities and quality of life [7].

Therefore, impairments in these abilities could negatively influence daily life activities and health-related quality of life over the lifespan, especially in a pathological population suchas PD subjects.

The evaluation of postural control and fine motor skills provides essential information about neuromuscular and motor coordination systems, particularly when neurodegenerative diseases are involved. Regarding postural control, several assessments are employed. Reaching tests, such as the Star Excursion Balance [8] and the Y Balance tests [9], are the most used due to their reliability and validity in evaluating dynamic postural control. Nevertheless, due to the multifaceted nature of the postural control evaluations, by reflecting the complexity of this ability, new approaches are needed to accurately evaluate dynamic posture. Recently, computerized unstable platforms equipped with triaxial accelerometers, such as Wobble Boards (WBs), have been suggested to be reliable [10] in the evaluation of dynamic balance in different populations using different physical tasks, such as monopodalic or bipodalic stance [11], and with or without visual biofeedback conditions [12]. To evaluate fine motor skills, tests used different tasks such as position changes (sitting or tandem position), time to complete the trial test or the number of transferred blocks during Box and Blocks Test [13], Peg test [14] and the Nine-Hole Peg test [15]. The National Institute of Health Toolbox for the Assessment of Neurological and Behavioral Function [16] indicated the Grooved Pegboard test (GPT) as gold standard because it is able to provide essential and accurate information about manual dexterity in PD [17,18]. Measures extrapolated from postural control and fine motor skills evaluations are used in clinical or field settings to evaluate specific properties in healthy subjects or to highlight the effects of several diseases on these complex abilities and, subsequently, organize individualized training protocols and promote appropriate levels of physical activity among individuals with PD. To increase postural control and fine motor skills, several training programs have been proposed. Studies [19–21] showed that postural control exercise protocols, including stepping, walking and/or monopodalic, bipodalic stances, are effective to improve postural control in older individuals with PD. Additionally, fine motor skills interventions (placing beads into a bottle, writing and painting) proved to elicit fine-manual dexterity function in PD patients [22,23].

The Parkinson's Foundation published the Parkinson's Exercise Guidelines for People with Parkinson's recommending, in particular, engagement in functional balance and coordination programs 2–3 days per week in 30–60 min sessions. PD subjects should perform static and dynamic exercises and multi-tasking training with daily integration, always considering safety procedures for subjects' care [24].

Therefore, the beneficial effects of physical activity programs, in particular combined exercise programs, represent the key factor to manage PD symptoms and delay the pathological and physical decline [25,26], as well as when home confinement is required [27]. Consequently, the aim of the present protocol will be to evaluate the effect of a combined exercise program on postural and fine motor skills using a training program in older adults with PD.

2. Materials and Methods

2.1. Participants

PD subjects (mild to moderate PD), aged between 65 to 80 years, will be voluntarily selected from Nursing Home Residences and Rehabilitation Centers located in the regional area.

Subjects will be only recruited after medical clearance to exercise, approved by theirmedical practitioner [28]. The project will be carried-out and presented in the above- mentioned location through a meeting where a detailed explanation of the experimentalprocedures will be given. Before starting the testing sessions, informed consent from participants or their guardians will be obtained. Subsequently, the Mini Mental State Examination Test Questionnaire for PD [29] will be administered to assess the degree ofpathology deterioration. The questionnaire includes seven ordered subsections (orientation, visual registration, attention/mental control, two-set verbal fluency, verbal recall, shifting and concept processing) with a total score of 30 (25–30 normal; 18–24 mild to moderate; <18 severe).

Subjects will be excluded if they: (a) have a score > 3 on the Hoehn and Yahr (H&Y) scale [30]; (b) have visual or musculoskeletal deficits; (c) have dementia or psychiatric abnormalities; (d) participate in any other medical or exercise interventions (additional to the usual received therapeutic treatment) during the study period; (e) be unable to carry outour motor performance tests independently and (f) have a Mini-Mental State Examination for PD score between 25–30 (normal) or <18 points (severe).

2.2. Procedures

2.2.1. Preliminary Evaluations

One week before the testing session, subjects' characteristics will be assessed. Body mass and height will be measured by means of a scale with integrated stadiometer with aprecision of 0.1 kg and 0.1 cm (Seca, model 709, Vogel & Halke, Hamburg, Germany), andbody mass index (BMI) will be calculated [31]. Waist circumference will be measured at the narrowest part of the abdominal region (if the narrowest part of the abdominal region is not clearly distinguishable, the waist will be measured midway between the 10th rib and the crest of the pelvic bone); hip circumference will be measured horizontally at the mostprotruding points in back of the gluteal region, side and front. Waist to hip ratio (WHR) will be calculated.

Subsequently, subjects will be recruited for the single-blind study and randomly allocated in two groups: PD group and Control group (CON group). PD group will participate in the combined training program; CON group will participate in a stretching program. Before (PRE) and after (POST) the combined training program (intervention)both groups will perform the tests (described in Section 2.2.3) in a randomized order. Participants in both groups will be instructed to continue with their usual care and advised not to change their daily activities during the trial. All the assessments will be carried out when participants will be in the "on" phase (i.e., when medications will be working and symptoms controlled).

Subjects will be able to withdraw from the study at any time for any reason withoutany consequences.

2.2.2. Sample Size

For the calculation of sample size, no a priori hypothesis was established due the lack of previous data regarding combined exercise program (postural control and fine moto skills) in subjects with PD. For this reason, a pilot study will be performed to estimate theeffect size (ES) of the intervention. The pilot study's recruitment goal will be 15 subjectswith PD for each group. Therefore, the ES, using Cohen's d, based on the results of the pilot study, will be determined. In line with similar research, an ES value less than 0.2 will considered trivial, from 0.2 to 0.5 small, greater than 0.5 to 0.8 moderate and greater than 0.8 large [32].

2.2.3. PRE and POST Evaluations

During this phase, all the subjects will perform a period of free practice with tests (WB and GPT) and procedures. The following test will be administered:

- Wobble Board

The platform is composed of a wooden circular table (diameter 40 cm, height 2 cm) placed on a hemispherical plastic support (diameter 28 cm, height 6 cm) and equipped with a USB connection cable. Connecting the board to a computer, it will be possible, through a proprietary software, to visualize six concentric circles and a yellow motion marker (MM) displayed in relation to the board tilt grade. The trial countdown, as well as the time spent into target zone (TZ), will be showed on the software screen. The TZ will be indicated by a red circle showing the 0° ($\pm 1^{\circ}$) tilt angle measured by the triaxial accelerometer. The evaluation will be performed for both lower and upper limbs.

The aim will be to keep the MM within the TZ for as long as possible during the recording period. The upper limbs' test session will consist of a 3-min familiarization on the WB (1 min sitting recovery) followed by three 15-s trials (right and left leg) with 1-min sitting recovery in between. During the test, the TZ will display different motion patterns: clockwise, counterclockwise, antero-posterior, medial-lateral. The lower limbs' test session will consist of a 3-min familiarization on the WB (1 min sitting recovery) followed by three attempts of 30 s per foot with one minute of rest in between [10]. During lower limb tests, subjects will be required to be in a seated position on a chair with back support with the hands resting on their legs and WB placed in front of the chair (Figure 1).

Figure 1. Standard lower limb Wobble Board test position.

During upper limb tests, subjects will be in a seated position, with the tested limb placed at 90° on the WB and the contralateral one (limb not performing the test) resting on the lower limb of the same side. The WB will be placed on a table and the monitor at eyelevel (Figure 2).

Figure 2. Standard upper limb Wobble Board test position.

The starting limb and the order of conditions will be randomly chosen.

The test trials will be stopped and repeated if the subjects: (1) use the arms for support;
(2) brace the raised leg against the contralateral leg; and (3) drop off the WB.

- Grooved Pegboard Test

The GPT (Lafayette Instrument, Lafayette, IN, USA; model 32025) is equipped with asqu×are pegboard (10 cm 10 cm) with 25 holes arranged in a 5 by 5 configuration, with random keyhole orientation and green steel pegs (diameter = 0.4 cm; model 32104) with a key along one side, located in a spherical tray above the keyholes. After the description of the testing procedures, the subjects will familiarize themselves with the task by filling only the first top row. Subsequently, subjects will be instructed to insert pegs one by one into the pegboard, as fast as possible, completing the rows from left to right for the right limb and from right to left for the left limb, from top to bottom (with 1-min recovery in between). Subjects will be free to perform trials when they prefer [33]. Only the dominant hand will be assessed, and all individuals with PD will perform the GPT two times. The recording time will start when subjects take the first peg and will stop when the last peg is inserted. The time to complete the GPT trials will be recorded by the operator using a digital stopwatch [18]. Lastly, if a peg falls, subjects will have to leave it and continue the test. The GPT will be placed on a table and subjects will be in a comfortable sitting position, with the contralateral limb (limb not performing the test) resting on the table (Figure 3).

Figure 3. Standard Grooved Pegboard test position.

2.2.4. Intervention

For 12 weeks, the PD group will receive at least one 60-min session twice a week of a supervised combined training program performed in the participating facilities. The PD group will perform a combined training program (balance and fine motor skills exercises), while the CON group will perform a stretching program. The stretching program will be adopted because of its positive applications in social and emotional aspects, in integrating real tasks from daily life activities and in improving overall physical aspects such as tremor, rigidity, bradykinesia, balance and motor coordination impairments, characterizing PD disease [34].

- PD group

The exercise sessions will include a 10-min warm-up and a cool-down of 5-min of walking, joint mobility (for upper and lower limbs) exercises in clockwise and counter- clockwise circling and breathing exercises and followed by 45 min postural control training. After each exercise, subjects will perform a 1-min break in a comfortable seated position. For postural control training, progression during the intervention period will be reached. For example, visual information will be trained by closing the eyes or looking up, down and sideward; proprioceptive system will be elicited using different unstable surfaces with respect to stable platforms and vestibular system will be disturbed using music or inhibited with appropriate earphones to isolate subjects from the external setting.

- Postural control exercises: bipodalic and monopodalic position (3 sets for 30-s (for limb)); stand up on the feet' sole (10 repetitions, 3 sets); stand up on heels (10 repetitions, 3 sets); calf raises (10 repetitions, 3 sets); hip abduction (12 repetitions, 3 sets); get up and sit down from a chair (5 repetitions); walking with stop (5 min); walking with change of direction (5 min); walking on a stable surfaces (5 min); walking on an unstable surfaces (5 min); walking with a tennis ball in hands (5 min) and walking and crossing several obstacles (5 min).

- Fine motor skills exercises for lower limbs: in sitting position, lift legs forward by placing a tennis ball between the feet trying not to let it fall (10 repetitions, 3 sets); sitting position and barefoot, grab and drop a towel with toes (for limb) (10 repetitions,3 sets); pass a tennis ball from foot to foot (20 steps); and in sitting position and barefoot,play a musical carpet (5 min) and toe raises with an elastic band (10 repetitions, 3 sets (for limb)).
- Fine motor skills for upper limbs: paper folding (5 repetitions, 3 sets); play a musical carpet (3 min); create shapes with paper (5 min); finger painting (5 min); trace a drawing (3 min); make bracelets (5 min); count coins and put in a moneybox; close a bottle (10 repetitions, 3 sets); press stamp on paper (10 repetitions, 3 sets); make lettersfrom plasticine (3 min); and press shaped blocks on plasticine (3 min).

- CON group

The exercise programs will include stretching exercises, as follows:

- Stretching during seated position: straight arm forward rotation; straight arm back-ward rotation; straight arm up and down flapping; straight arm horizontal abduction and adduction; trunk rotation and hold. During standing position (with hands rest on chair back): hamstring stretch; calf stretch; upper trapezius stretch; straight leg forward kick; straight leg backward kick; straight leg hip adduction and abduction; and alternate knee raise (30-s, 2 cycles with 20 s rest in between) [35].

2.2.5. Work Environment and Safety of Procedures

The project will be conducted in the selected Nursing Home Residences and Rehabilitation Centers. To ensure adequate safety standards, the setting designated for the protocol will be equipped with a first aid kit and a semiautomatic defibrillator. Given the progressive cognitive and physical function decline of PD, a neurologist will supervise thestudy protocol and during each test session, and physical exercise experts will take care of the subjects' due precautions, such as soft surfaces, harnesses and various aids, to ensure the safety of each PD individual. Moreover, preventive measures will be taken to prevent the risk of Coronavirus disease 2019 (COVID-19) transmission. The designed setting will be periodically sanitized, and testing surfaces will be cleaned with alcohol-based disinfectants before and after each use. Lastly, the use of masks (FFP2) and gloves by the specialists will be mandatory.

2.2.6. Statistical Analysis

To ensure confidentiality and protection of personal data, subjects' data will be de- identified indicating a numerical code for each participant.

The 'Intervention' will be considered as an independent variable, whereas WB and GPT will be considered as dependent variables. The collected data for the analysis of WBand GPT will be expressed in time in seconds (s). Means and SDs will be calculated for each variable. The normal distribution of data will be assessed by the Shapiro–Wilk test. If data are normally distributed, parametric statistical analysis (Analysis of Variance (ANOVA) for repeated measures) will be performed. If data are not normally distributed, non-parametric statistical analysis (Kruskal–Wallis ANOVA for ranked data) will be performed. Therefore, the appropriate analysis will be used to test for differences between PD and CON groups over time (PRE and POST).

In line with previous research, statistical significance will be set at a level of $p < 0.05$. The data will be analyzed using STATA 15 (StataCorp LP, College Station, TX, USA). In addition, the intervention will be considered effective if the evaluated variables (WB and GPT) show improvements in the PD group compared to the CON one.

3. Discussion

The purpose of the present study will be to evaluate the effect of a combined trainingprogram in older adults with PD. In particular, the proposed 12-week training program will aim to improve postural control and fine motor coordination in mild to moderate PDsubjects.

PD is commonly considered as a form of "accelerated aging" of the nervous system affecting subjects' ability to control movements with tremor disorders [36,37]. The major characteristics of PD are impairments in movement while resting or moving, rigidity [36]and more difficulties in executing simultaneous movements and sequential tasks with respect to simple ones [5]. In particular, the progression of PD leads to a phenomenon calledfestination, resulting in a decrease in gait speed and an increase in the rate of falls with a consequent loss of independency [5]. Moreover, several studies have reported the negative association between fine motor skills, especially hand disability, and cognitive dysfunction in the PD population [38,39]. In fact, the dopamine neuron depletion caused by PD influences various domains of executive functions, motor coordination and psychomotorspeed [40]. These functional disabilities compromise the regular daily activities requiredfor dressing, ascending or descending steps, to self-take care and/or walking. Therefore,the implementation of training interventions to improve postural control and fine motor coordination in PD subjects is fundamental.

Studies proposed several kinds of training programs to improve these abilities in subjects with PD. In the last decade, evidence supported dance activities, aquatic-based exercise and oriental disciplines as effective symptom management modalities. It emerged, in fact, that dance classes could improve functional abilities [41], quality of life [42] and activities of daily living in a PD population [43]. About oriental disciplines, Tai Chi resulted in promising gains in mobility and balance, and it was demonstrated to be safe and popular among subjects with PD at an early stage of the disease [44]. Furthermore, aquatic exercise improves the motor impairments of PD, and it seems to achieve greater benefits than land-based exercise on balance capacity, fear of falling and health-related quality of life in PD populations with a mild to moderate degree of disability [45].

On the other hand, among different single training protocols, combined exercise pro-grams (postural control and fine motor skills exercises) might be more effective. In fact, intervention protocols including several physical activities such as multidirectional stride training, climbing and descending, stretching forward and sideways, obstacles, turning around, stepping, getting up and sitting down, specific trunk rehabilitation exercises, pas-sive spinal joints mobilization, writing, drawing, bouncing a ball during gait, maintaining balance while standing on stable and unstable support bases of different consistency and walking with open or closed eyes are commonly used approaches, which show improve-ments in muscle activation, fine coordination and postural control and decrease the risk of falls [19–23,46,47].

In line with such evidence, we hypothesized that different performances between groups will expected: (1) no significant differences between PD and CON group for WB and GPT test values before the beginning of the training intervention (PRE-intervention);
(2) significantly better WB and GPT test values in PD subjects after the training intervention (POST-intervention) when compared to the base values (PRE-intervention); and (3) no significant differences in WB and GPT test values in CON subjects after the training intervention (POST-intervention) when compared to the base values (PRE-intervention).Therefore, thanks to the future findings of the present study, health professionals could provide individualized training protocols to improve postural control, fine motor skills and perform a regular level of physical activity [24]. Moreover, WB and GPT tests could be practical, inexpensive, administrable and accurate tools to provide essential and useful information about the evaluation of postural control and fine motor skills, especially in light of the progressive degenerative course of PD.

4. Conclusions

Cognitive status is strongly associated with postural control and fine motor skills insubjects with PD. With the progression of PD, the most common symptoms are movement- related tremor, rigidity, slowness of movement, postural instability, difficulty with walking and gait and difficulty in motor coordination affecting quality of life. For this reason, training protocols, due their beneficial effects in improving postural control and fine skills, are widely used in PD. Combined postural control and fine motor skills interventions are particularly useful in preventing falls, improving fine coordination and quality of life. In conclusion, the findings of the present study protocol could be used for future comparison studies investigating such a clinical population and the effects of different rehabilitative interventions aiming to improve postural control and fine motor skills performances assessed by WB and GPT tests.

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Informed Consent Statement: Informed consent will be obtained from all subjects willing to be involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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General discussion

This thesis was organized into three parts, aiming at 1) measuring wobble performance in individuals with unilateral CAI; 2) investigating the effect of anthropometric characteristics, sex, and VBF; and 3) evaluating dynamic balance and fine motor skills performances in PD subjects.

The main findings that emerged from the first study were that when measuring WB performances in CAI subjects, the major predictors were ankle and knee angular-displacement parameters, body height and lower limb length variables. Furthermore, among the extrapolated models, only the T1 model was able to detect WB performance differences between the injured and uninjured limb in individuals with unilateral CAI, respect to T2 and T3 only able to detect healthy subjects. In line with previous researches [1, 2] ankle, independently from the time-segment video analyzed, and knee angular-displacement played major roles on the WB performance and the accuracy of the predicting models extrapolated. In fact, the control of standing dynamic balance during single leg stance task relies on the control of ankles with increasing contributions of proximal joints as the balance demands become more challenging. Regarding the anthropometric variables, only body height and lower limb length had an influence on the dynamic performances on the WB. Although, literature suggested that these variables affected the dynamic balance particularly in reaching tests as YBT [3], in this case, they represent the major predictor in the extrapolated equation models to quantify dynamic performances. However, focused on body height, the results are in line with Greve and colleagues [4], which demonstrated that this variable had moderate correlation in dynamic balance performances. Thus, these findings confirmed that ankle displacements increased with body height [5-7]. Furthermore, a strong correlation was found in the developed equations. In fact, the consistency and precision of the extrapolated models represent an indirect method for quantify WB performances in uninjured limb with T1 T2 and T3 models and in injured limbs with T1 model. Therefore, extrapolated equation have the potential in measuring WB performances also in uninjured population. Despite the meaningful results of our investigation, some limits need to be acknowledged. The sample was limited to healthy young adults and subjects with unilateral CAI, and therefore other populations, such as older adults or other clinical populations, could have different predictors and results for the WB performance.

Regarding of the anthropometric characteristics, sex, VBF, the second study aimed to evaluate the effect of the above-mentioned variables and their interaction on computerized WB. The main finding from this study highlighted that VBF may improve WB balance performance with respect to the NVBF condition in healthy young adults. According to several investigations [8-13], VBF condition enhance dynamic performances in judo athletes, young karatekas, healthy subjects, young adults and elderly people. In fact, it is well documented that standing on an unstable platform results in changes in sensory biofeedback and subjects increasing their reliance on visual information. Therefore, the postural control could be more efficient in the VBF condition when standing on an unstable platform. Literature also suggests that visual information changes the relationship between anthropometrics and the postural sway [6]. In line with a previous study [6] a greater correlation between postural sway and body mass was found when the balance test was performed during eye opened condition. However, in other studies [14, 15], postural sway increased in NVBF conditions such as balance tests with eyes closed probably due to the difference in the NVBF modality. In fact, although the eyes closed condition might be included in the NVBF category, there might be a difference in terms of difficulty between having a visual cue with eyes open (a mark on a black board) and the eyes closed with no visual orientation. In addition, for the VBF condition, significant effects were also found for sex and body mass and sex and MI. An explanation about this result might be found in the test execution. Although, the test protocol was standardized in terms of execution, no indications were provided about the trunk control. For this reason, it might have happened that during the test execution of WB test the subjects leaned forward or backward with their trunks in order to focus on the screen to keep their balance flat, and as MI estimates the subjects' whole body MI on the frontal axis through the centre of mass, this further centre of mass displacement might have influenced the performance during the VBF condition. A significant main effect of HTR, sex, and their interaction on the NVBF condition WB performance was also found. Generally, limbs' length, has shown a positive correlation in postural sway in both eyes opened and closed conditions attributing positive relationship to reaching tests [16]. Commonly, taller individuals, more evident in males, tend to have longer lower limbs, and this condition is often associated with a greater distance between the centre of mass and BoS, resulting in a higher postural sway [17]. Conversely, in the present study, a negative relationship related to sex was found. In particular, at higher HTR values, men increased their dynamic balance performance, while women decreased it. Alonso and colleagues [6] suggested that this difference between sexes could be due to greater anthropometric variables, lower flexibility, and slower neurophysiologic processing of inferences in men. Therefore, unstable platform as WB model has the potential in detecting which sources of variability have more influence on the dynamic balance assessment. Nevertheless, several limitations need to be acknowledged for this study. Further research are need, because it could be possible that other VBF strategies might have a different influence on WB performances.

The aging process also affects dynamic balance, and the third protocol study aims to evaluate the effect of a combined exercise program (balance and fine motor skills) on postural and fine motor skills using a training program in older adults with PD. The beneficial effects of physical activity programs, in particular combined exercise programs, was well documented. Physical activity also represent the key factor to manage PD symptoms and delay both pathological and physical decline [18, 19]. Recently, evidence supported dance activities, aquatic-based exercise and oriental disciplines as effective symptom management modalities [20-22]. However, combined exercise programs seems to be more effective than single training program showing improvements in muscle activation, fine coordination, postural control and decrease the risk of falls [23, 24]. Therefore, In line with such evidence it was hypothesized that combined exercise program could have a beneficial effect on dynamic and fine motor abilities. In particular, it was expected no significant differences between PD and CON group for WB and GPT test values before the beginning of the training intervention; significantly better WB and GPT test values in PD subjects after the training intervention when compared to the base values; and no significant differences in WB and GPT test values in CON subjects after the training intervention when compared to the base values. Thus, in this contest, the evaluation of these abilities become important. In fact, WB and GPT tests could be practical, inexpensive, administrable and accurate tools to provide essential and useful information about the evaluation of postural control and fine motor skills, especially for pathological population as PD. Lastly, thanks to the future findings of the present study, health professionals could provide individualized training protocols to improve postural control and fine motor skills.

General conclusion

The main findings of this project were that the computerized WB are reliable and accurate tool in evaluating dynamic balance and in measuring WB performance in healthy and injured adults. In particular, the results highlighted that WB's measures are affected by other sources of variability as anthropometric variables, sex, cognitive processes like VBF and neurodegenerative diseases. Therefore, WB can be used in clinical and field settings to accurate detect and measure dynamic balance performances in different population.

Since WBs are easy to set and interpret, they have the potential in screening, measuring and quantifying dynamic balance performances and its progression in long-time, filling the gap between laboratory and field settings. Additionally, the affordability, transportability and specificity of WBs making data collection on balance performances feasible for health scientists and/or coaches looking for inexpensive, portable, reliable, and valid assessment tools.

From a practical point of view, results from the present project could have an impact on training and evaluations protocols, especially when several populations such as children, athletes, older adults, people with balance disorders and neurodegenerative disorders are involved. Therefore, the computerized WBs become essential tools for dynamic balance assessment.

Future directions

Based on the findings of this project and the potentiality of WBs in evaluating and measuring dynamic balance performances, future research should address other main component of the WBs performances. In particular, studies could evaluated the effect of several conditions as acoustic feedback and non-acoustic feedback and anthropometrics as foot or limbs length. Furthermore, future studies should investigate the reliability and validity of WBs in detecting balance deficit in other population as athletes (e.g. dancers, volleyball, handball and basketball players and runners) or pathological one as Alzheimer or multiple sclerosis. In conclusion, future research should clearly determine which factor would have more impact on WB performances.

Practical implications

- WB is a reliable and valid tool in evaluating dynamic balance performances;
- WB is accurate to detect the injured limb in individuals with unilateral CAI;
- The equations extrapolated from WB may provide different methods to quantify dynamic performances;
- Anthropometric variables and sex affect WB performances;
- Cognitive process as VBF improve WB performances;
- The affordability and transportability of WB are key factors during filed evaluations;
- WB can fill the gap between laboratory and field settings;
- WB could be reliable and valid to assess balance and fine motor skills performances in PD subjects;
- WB is practical, inexpensive, administrable and accurate tool to provide essential and useful information about the evaluation of dynamic balance performances in several populations.

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List of publications

1. **De Maio M.**, Di Rocco F., Papale O., Festino E., Cortis C., Fusco A. Could Mini-Trampoline Training Be Considered as a New Strategy to Reduce Asymmetries? (2023). *Applied Sciences*. 13(5), 3193. https://doi.org/10.3390/app13053193
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1. Fusco A., Fuchs P.X., Giancotti G.F., **De Maio M.**, Varalda C., Wagner H., Capranica L., Cortis C. Wobble Board Dynamic Assessment in Subjects with Chronic Ankle Instability. 65th Annual Meeting of the American College of Sports Medicine, Minneapolis (Minnesota, USA), 29 May-2 June. Medicine and Science in Sport and Exercise, 49(5S), p. 424-425;
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‘Sarà un percorso fatto di gioie e pianti,

ma uno dei più belli da ricordare’