Article

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

Marianna De Maio [1], Cristina Cortis [1],*, Alice Iannaccone [1], Rubens A. da Silva [2,3] and Andrea Fusco [1]

[1] Department of Human Sciences, Society and Health, University of Cassino e Lazio Meridionale, Viale dell'Università, 03043 Cassino, Italy; marianna.demaio@unicas.it (M.D.M.); alice.iannaccone@unicas.it (A.I.); andrea.fusco@unicas.it (A.F.)

[2] Département Sciences de la Santé, Lab BioNR, CISD, Université du Québec à Chicoutimi (UQAC), 555 boul. de l'Université, Chicoutimi, QC G7H 2B1, Canada; rubens_dasilva@uqac.ca

[3] Centre Intégré Universitaire de Santé et de Services Sociaux du Saguenay, 1000 Rue du Docteur Desgagné, La Baie, Chicoutimi, QC G7B 2Y6, Canada

* Correspondence: c.cortis@unicas.it

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

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 body mass [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 mass was computed using the following Equation (1) [35]:

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

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 the lower 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 conditions was 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 (kg/m^2)	21.2 ± 1.7	24.4 ± 1.9	22.8 ± 0.1

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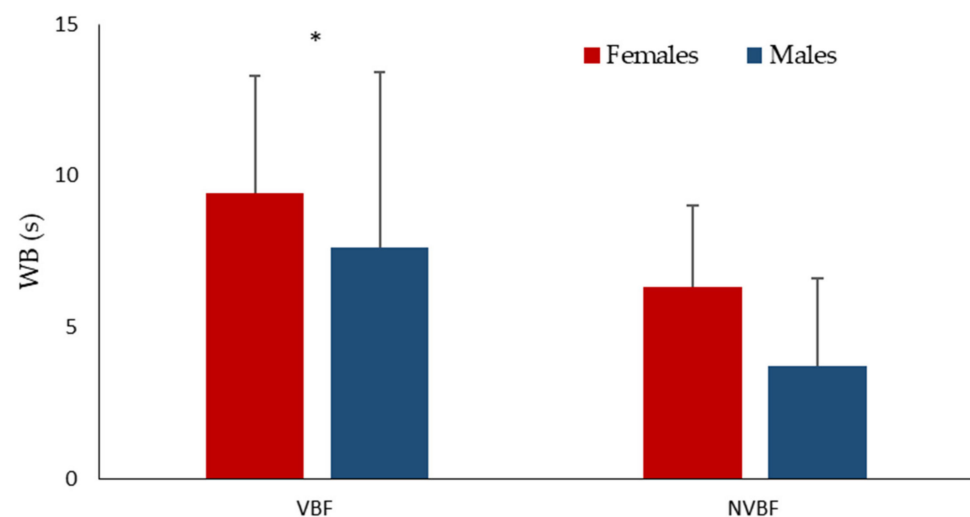
Figure 1. Means and standard deviations of wobble board balance performances (WB) for visual biofeedback (VBF) and no visual biofeedback (NVBF) in both sexes. * significantly different from the no visual biofeedback (NVBF) in male and female.

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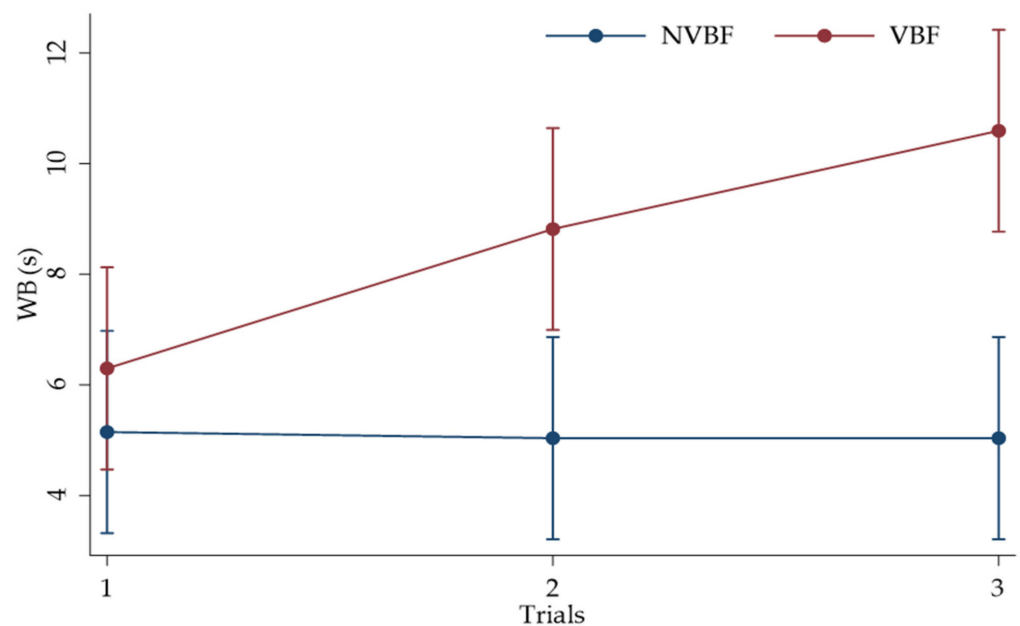
Figure 2. Wobble board (WB) performance trend over trials for the visual biofeedback (VBF) and no visual biofeedback (NVBF) conditions.

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	$p > \lvert z \rvert$	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	$p > \lvert z \rvert$	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	$p > \lvert z \rvert$	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.
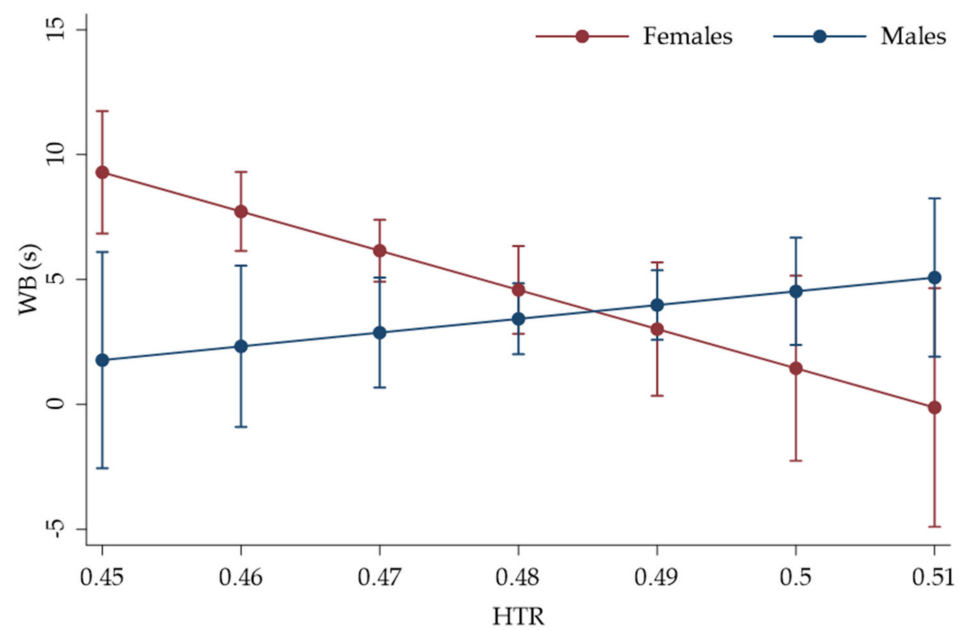
Figure 3. The interaction of lower limb/height ratio (HTR) and sex in the no visual biofeedback (NVBF) condition.
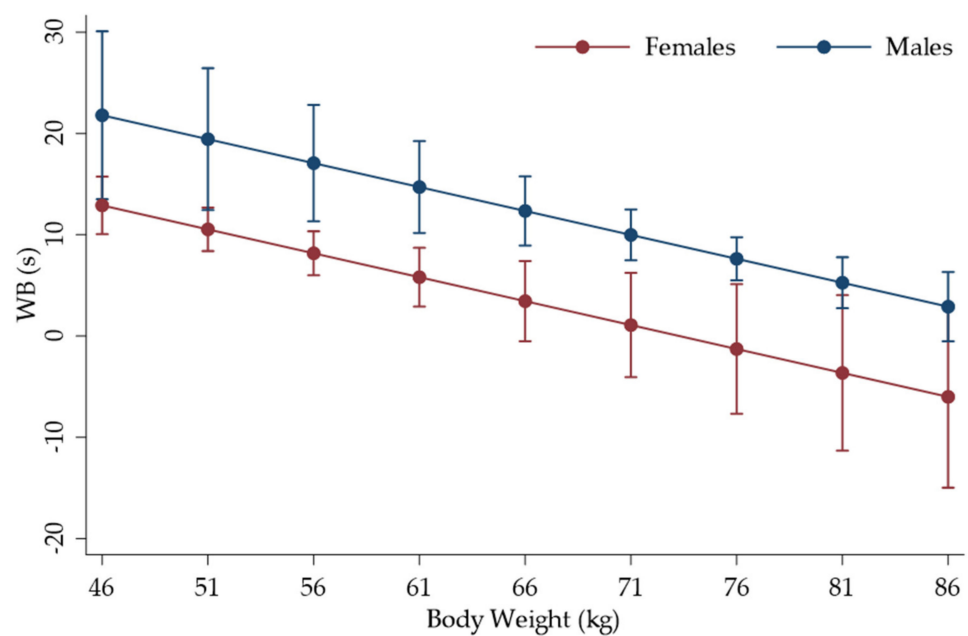
Figure 4. Main effect of body mass on the wobble board performance (WB) during the visual biofeedback (VBF) condition in relation to sex.
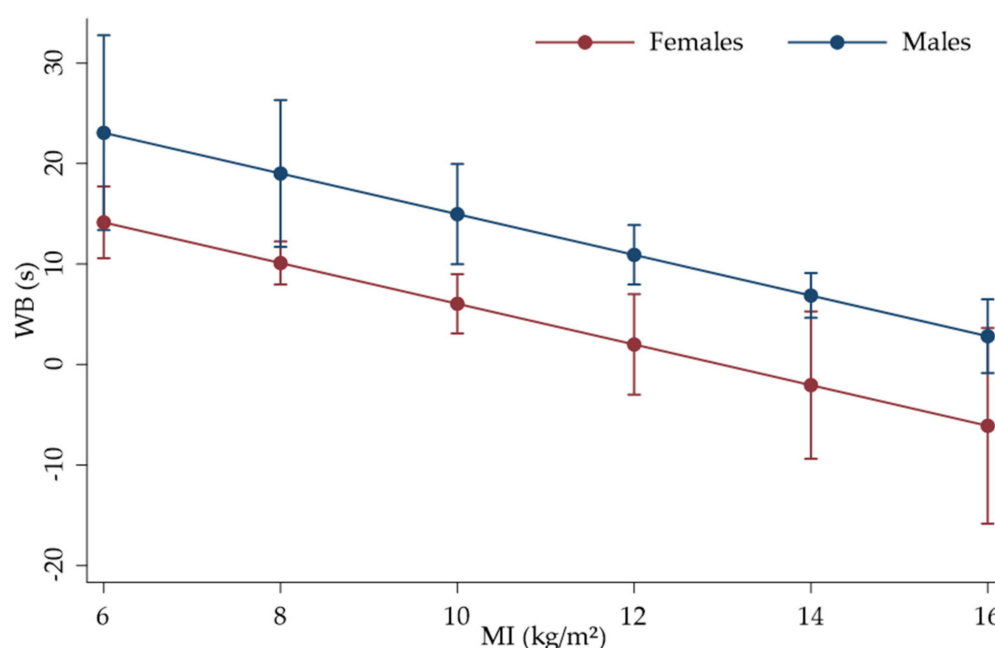
Figure 5. Main effect of whole-body moment of inertia (MI) on the wobble board performance (WB) during the visual biofeedback (VBF) condition in relation to sex.

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 studies are 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 correlation between 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 body mass 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 the NVBF 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 cannot confirm 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 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. 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 effect of anthropometric characteristics, sex, VBF and NVBF, and their interaction on WB.

References

1. Pollock, A.S.; Durward, B.R.; Rowe, P.J.; Paul, J.P. What is balance? *Clin. Rehabil.* **2000**, *14*, 402–406. [CrossRef] [PubMed]
2. Horak, F.B. Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age Ageing* **2006**, *35*, ii7–ii11. [CrossRef] [PubMed]
3. Yim-Chiplis, P.K.; Talbot, L.A. Defining and Measuring Balance in Adults. *Biol. Res. Nurs.* **2000**, *1*, 321–331. [CrossRef] [PubMed]
4. McGraw, B.; McClenaghan, B.A.; Williams, H.G.; Dickerson, J.; Ward, D.S. Gait and postural stability in obese and nonobese prepubertal boys. *Arch. Phys. Med. Rehabil.* **2000**, *81*, 484–489. [CrossRef] [PubMed]
5. Pereira, C.; da Silva, R.A.; de Oliveira, M.R.; Souza, R.D.N.; Borges, R.J.; Vieira, E.R. Effect of body mass index and fat mass on balance force platform measurements during a one-legged stance in older adults. *Aging Clin. Exp. Res.* **2018**, *30*, 441–447. [CrossRef]
6. Chiari, L.; Cappello, A.; Lenzi, D.; Della Croce, U. An improved technique for the extraction of stochastic parameters from stabilograms. *Gait Posture* **2000**, *12*, 225–234. [CrossRef]
7. Fusco, A.; Giancotti, G.F.; Fuchs, P.X.; Wagner, H.; da Silva, R.A.; Cortis, C. Y balance test: Are we doing it right? *J. Sci. Med. Sport* **2020**, *23*, 194–199. [CrossRef] [PubMed]
8. Singh, D.; Park, W.; Levy, M.S.; Jung, E.S. The effects of obesity and standing time on postural sway during prolonged quiet standing. *Ergonomics* **2009**, *52*, 977–986. [CrossRef] [PubMed]
9. Alonso, A.C.; Mochizuki, L.; Silva Luna, N.M.; Ayama, S.; Canonica, A.C.; Greve, J.M.D.A. Relation between the Sensory and Anthropometric Variables in the Quiet Standing Postural Control: Is the Inverted Pendulum Important for the Static Balance Control? *Biomed Res. Int.* **2015**, *2015*, 985312. [CrossRef] [PubMed]
10. Nolan, L.; Grigorenko, A.; Thorstensson, A. Balance control: Sex and age differences in 9- to 16-year-olds. *Dev. Med. Child Neurol.* **2005**, *47*, 449–454. [CrossRef] [PubMed]
11. Hue, O.; Simoneau, M.; Marcotte, J.; Berrigan, F.; Doré, J.; Marceau, P.; Marceau, S.; Tremblay, A.; Teasdale, N. Body weight is a strong predictor of postural stability. *Gait Posture* **2007**, *26*, 32–38. [CrossRef]

12. Mainenti, M.R.M.; Rodrigues, É.D.; de Oliveira, J.F.; Ferreira, A.D.; Dias, C.M.; Silva, A.L.D.S. Adiposity and postural balance control: Correlations between bioelectrical impedance and stabilometric signals in elderly Brazilian women. *Clinics* **2011**, *66*, 1513–1518. [PubMed]

13. Yoshida, K.; Iwakura, H.; Inoue, F. Motion analysis in the movements of standing up from and sitting down on a chair. A comparison of normal and hemiparetic subjects and the differences of sex and age among the normals. *Scand. J. Rehabil. Med.* **1982**, *15*, 133–140.

14. Masui, T.; Hasegawa, Y.; Matsuyama, Y.; Sakano, S.; Kawasaki, M.; Suzuki, S. Gender differences in platform measures of balance in rural community-dwelling elders. *Arch. Gerontol. Geriatr.* **2005**, *41*, 201–209. [CrossRef]

15. Bryant, E.C.; Trew, M.E.; Bruce, A.M.; Kuisma, R.M.E.; Smith, A.W. Gender differences in balance performance at the time of retirement. *Clin. Biomech.* **2005**, *20*, 330–335. [CrossRef] [PubMed]

16. Cortis, C.; Pesce, C.; Capranica, L. Inter-limb coordination dynamics: Effects of visual constraints and age. *Kinesiology* **2018**, *50*, 133–139.

17. Dozza, M.; Chiari, L.; Horak, F.B. Audio-Biofeedback Improves Balance in Patients With Bilateral Vestibular Loss. *Arch. Phys. Med. Rehabil.* **2005**, *86*, 1401–1403. [CrossRef] [PubMed]

18. Cornwell, T.; Woodward, J.; Wu, M.; Jackson, B.; Souza, P.; Siegel, J.; Dhar, S.; Gordon, K.E. Walking With Ears: Altered Auditory Feedback Impacts Gait Step Length in Older Adults. *Front. Sport. Act. Living* **2020**, *2*, 38. [CrossRef]

19. Halická, Z.; Lobotková, J.; Bučková, K.; Hlavačka, F. Effectiveness of different visual biofeedback signals for human balance improvement. *Gait Posture* **2014**, *39*, 410–414. [CrossRef]

20. Cheng, P.-T.; Wang, C.-M.; Chung, C.-Y.; Chen, C.-L. Effects of visual feedback rhythmic weight-shift training on hemiplegic stroke patients. *Clin. Rehabil.* **2004**, *18*, 747–753. [CrossRef]

21. Dault, M.C.; de Haart, M.; Geurts, A.C.; Arts, I.M.; Nienhuis, B. Effects of visual center of pressure feedback on postural control in young and elderly healthy adults and in stroke patients. *Hum. Mov. Sci.* **2003**, *22*, 221–236. [CrossRef]

22. Rougier, P.; Boudrahem, S. Effects of visual feedback of center-of-pressure displacements on undisturbed upright postural control of hemiparetic stroke patients. *Restor. Neurol. Neurosci.* **2010**, *28*, 749–759. [CrossRef] [PubMed]

23. Sackley, C.M.; Lincoln, N.B. Single blind randomized controlled trial of visual feedback after stroke: Effects on stance symmetry and function. *Disabil. Rehabil.* **1997**, *19*, 536–546. [CrossRef] [PubMed]

24. Walker, C.; Brouwer, B.J.; Culham, E. Use of visual feedback in retraining balance following acute stroke. *Phys. Ther.* **2000**, *80*, 886–895. [CrossRef] [PubMed]

25. Winstein, C.; Gardner, E.; McNeal, D.; Barto, P.; Nicholson, D. Standing balance training: Effect on balance and locomotion in hemiparetic adults. *Arch. Phys. Med. Rehabil.* **1989**, *70*, 755–762.

26. Kennedy, M.W.; Crowell, C.R.; Striegel, A.D.; Villano, M.; Schmiedeler, J.P. Relative efficacy of various strategies for visual feedback in standing balance activities. *Exp. Brain Res.* **2013**, *230*, 117–125. [CrossRef] [PubMed]

27. Haas, B.M.; Burden, A.M. Validity of weight distribution and sway measurements of the Balance Performance Monitor. *Physiother. Res. Int.* **2000**, *5*, 19–32. [CrossRef]

28. Olmsted, L.C.; Carcia, C.R.; Hertel, J.; Shultz, S. Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *J. Athl. Train.* **2002**, *37*, 501–506. [PubMed]

29. Hertel, J.; Braham, R.A.; Hale, S.A.; Olmsted-Kramer, L.C. Simplifying the Star Excursion Balance Test: Analyses of Subjects With and Without Chronic Ankle Instability. *J. Orthop. Sport. Phys. Ther.* **2006**, *36*, 131–137. [CrossRef]

30. Laessoe, U.; Svendsen, A.W.; Christensen, M.N.; Rasmussen, J.R.; Gaml, A.S. Evaluation of functional ankle instability assessed by an instrumented wobble board. *Phys. Ther. Sport* **2019**, *35*, 133–138. [CrossRef] [PubMed]

31. Fusco, A.; Giancotti, G.F.; Fuchs, P.X.; Wagner, H.; Varalda, C.; Capranica, L.; Cortis, C. Dynamic Balance Evaluation: Reliability and Validity of a Computerized Wobble Board. *J. Strength Cond. Res.* **2020**, *34*, 1709–1715. [CrossRef] [PubMed]

32. Williams, J.; Bentman, S. An investigation into the reliability and variability of wobble board performance in a healthy population using the SMARTwobble instrumented wobble board. *Phys. Ther. Sport* **2014**, *15*, 143–147. [CrossRef] [PubMed]

33. Fusco, A.; Fuchs, P.X.; De Maio, M.; Wagner, H.; Cortis, C. A novel approach to measuring wobble board performance in individuals with chronic ankle instability. *Heliyon* **2020**, *6*, e04937. [CrossRef] [PubMed]

34. Fusco, A.; Giancotti, G.F.; Fuchs, P.X.; Wagner, H.; Varalda, C.; Cortis, C. Wobble board balance assessment in subjects with chronic ankle instability. *Gait Posture* **2019**, *68*, 352–356. [CrossRef] [PubMed]

35. Matsuo, A.; Ozawa, H.; Goda, K.; Fukunaga, T. Moment of inertia of whole body using an oscillating table in adolescent boys. *J. Biomech.* **1995**, *28*, 219–223. [CrossRef]

36. Kręcisz, K.; Kuczyński, M. Attentional demands associated with augmented visual feedback during quiet standing. *PeerJ* **2018**, *6*, e5101. [CrossRef]

37. Inojosa, H.; Schriefer, D.; Trentzsch, K.; Klöditz, A.; Ziemssen, T. Visual Feedback and Postural Control in Multiple Sclerosis. *J. Clin. Med.* **2020**, *9*, 1291. [CrossRef]

38. Emami Meibodi, M.K.; Naghizad, J.; Shamsoddini, A. The effect of balance rehabilitation interventions with and without visual feedback on balance and proprioception of knee in patients with anterior cruciate ligament injury: A randomized clinical trial. *Sport Sci. Health* **2021**. [CrossRef]

39. Pignolo, L.; Basta, G.; Carozzo, S.; Bilotta, M.; Todaro, M.R.; Serra, S.; Ciancarelli, I.; Tonin, P.; Cerasa, A. A body-weight-supported visual feedback system for gait recovering in stroke patients: A randomized controlled study. *Gait Posture* **2020**, *82*, 287–293. [CrossRef]

40. Wan, Y.; Davies, J.L.; Button, K.; Al-Amri, M. Effect of visual feedback on the performance of the star excursion balance test. *J. Rehabil. Assist. Technol. Eng.* **2019**, *6*, 205566831986213. [CrossRef]

41. Kons, R.L.; Sakugawa, R.L.; Rossato, M.; Diefenthaeler, F.; Detanico, D. Neuromuscular and postural control in visually and nonvisually impaired judo athletes: Case study. *J. Exerc. Rehabil.* **2019**, *15*, 60–66. [CrossRef] [PubMed]

42. Vando, S.; Longo, S.; Cavaggioni, L.; Maurino, L.; Larion, A.; Invernizzi, P.L.; Padulo, J. The Effects of Short-Term Visual Feedback Training on the Stability of the Roundhouse Kicking Technique in Young Karatekas. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1961. [CrossRef]

43. D'Anna, C.; Schmid, M.; Bibbo, D.; Bertollo, M.; Comani, S.; Conforto, S. The Effect of Continuous and Discretized Presentations of Concurrent Augmented Visual Biofeedback on Postural Control in Quiet Stance. *PLoS ONE* **2015**, *10*, e0132711. [CrossRef]

44. Bechly, K.E.; Carender, W.J.; Myles, J.D.; Sienko, K.H. Determining the preferred modality for real-time biofeedback during balance training. *Gait Posture* **2013**, *37*, 391–396. [CrossRef] [PubMed]

45. Alhasan, H.; Hood, V.; Mainwaring, F. The effect of visual biofeedback on balance in elderly population: A systematic review. *Clin. Interv. Aging* **2017**, *12*, 487–497. [CrossRef]

46. Cawsey, R.P.; Chua, R.; Carpenter, M.G.; Sanderson, D.J. To what extent can increasing the magnification of visual feedback of the centre of pressure position change the control of quiet standing balance? *Gait Posture* **2009**, *29*, 280–284. [CrossRef] [PubMed]

47. Chiari, L.; Rocchi, L.; Cappello, A. Stabilometric parameters are affected by anthropometry and foot placement. *Clin. Biomech.* **2002**, *17*, 666–677. [CrossRef]

48. Winter, D.A.; Patla, A.E.; Ishac, M.; Gage, W.H. Motor mechanisms of balance during quiet standing. *J. Electromyogr. Kinesiol.* **2003**, *13*, 49–56. [CrossRef]

49. King, A.C.; Challis, J.H.; Bartok, C.; Costigan, F.A.; Newell, K.M. Obesity, mechanical and strength relationships to postural control in adolescence. *Gait Posture* **2012**, *35*, 261–265. [CrossRef] [PubMed]

50. Alonso, A.; Luna, N.; Mochizuki, L.; Barbieri, F.; Santos, S.; D'Andreia Greve, J. The influence of anthropometric factors on postural balance: The relationship between body composition and posturographic measurements in young adults. *Clinics* **2012**, *67*, 1433–1441. [CrossRef]

51. Kejonen, P.; Kauranen, K.; Vanharanta, H. The relationship between anthropometric factors and body-balancing movements in postural balance. *Arch. Phys. Med. Rehabil.* **2003**, *84*, 17–22. [CrossRef]

52. Wikstrom, E.A. Validity and Reliability of Nintendo Wii Fit Balance Scores. *J. Athl. Train.* **2012**, *47*, 306–313. [CrossRef]

53. Wrisley, D.M.; Stephens, M.J.; Mosley, S.; Wojnowski, A.; Duffy, J.; Burkard, R. Learning Effects of Repetitive Administrations of the Sensory Organization Test in Healthy Young Adults. *Arch. Phys. Med. Rehabil.* **2007**, *88*, 1049–1054. [CrossRef] [PubMed]

54. Fransson, P.-A.; Tjernström, F.; Hafström, A.; Magnusson, M.; Johansson, R. Analysis of short- and long-term effects of adaptation in human postural control. *Biol. Cybern.* **2002**, *86*, 355–365. [CrossRef] [PubMed]

55. Fransson, P.A.; Johansson, R.; Tjernstrom, F.; Magnusson, M. Adaptation to vibratory perturbations in postural control. *IEEE Eng. Med. Biol. Mag.* **2003**, *22*, 53–57. [CrossRef] [PubMed]