Effectiveness of perceptual training - proprioceptive feedback in a virtual visual diverse group of healthy subjects: a pilot study

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ABSTRACT

BACKGROUND: the aim of this pilot study was to evaluate whether proprioceptive-motor training using the Wii Balance Board (WBB) might improve postural sway in healthy subjects.

METHODS: twenty-five healthy subjects were trained for six weeks (two sessions per week) with 5 "video games": Wii Fit Plus (WFP) program. Before and after training: Basic Balance, Single-leg Balance, Agility, Stability and Motion (lower limb: right-left and both leg) were measured using the Wii Balance Board.

RESULTS: the Wilcoxon Test showed improvements at the end of the training program compared to the baseline conditions. Basic Balance increased during the WFP (33.33%) and was associated with a 19.92% decrease in center of pressure (COP) lenght. The Single-leg Balance results incremented after the WFP (left 29.09% vs. right 47.92%) and accompanied by a decrement in COP (left 28.71% vs. right 30.45%). The values for the Agility test increased both in WFP and COP (28.57% and 58.57%, respectively). The Stability test scores increased in the WFP (66.67%) along with a consequent decrease in COP (10.53%). Finally, the Motion test values increased in the WFP (73.17%), whilst COP for this test decreased (12.02%). These results indicate that 6 weeks of virtual training produced a good adaptability. Younger participants (<20 years) demonstrated to be more responsive to dynamic stimulation with respect to those >20 years.

CONCLUSIONS: significant improvements in all participants were observed, indicating that virtual training can influence posture and balance in healthy people. Because of its characteristics of low cost and easy availability, a portable system for balance training for everyone offers the possibility to more readily measure motor skill and to gauge improvement.

Key words: Proprioception; Interactivity; Wii Balance Board; Platform force feedback; Motor control; Virtual training; Adaptability

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INTRODUCTION

Modern society has the conviction that exercise and movement is synonymous with health and wellness. Many companies have been concentrating their efforts on those aspects for years, and this has purposely led to the development and commercialization of modern interactive video games. The developments in Virtual Reality (VR), which is an immersive, interactive, 3-dimensional realm, provide us with powerful technology for the monitoring of motor control in real-time [1].

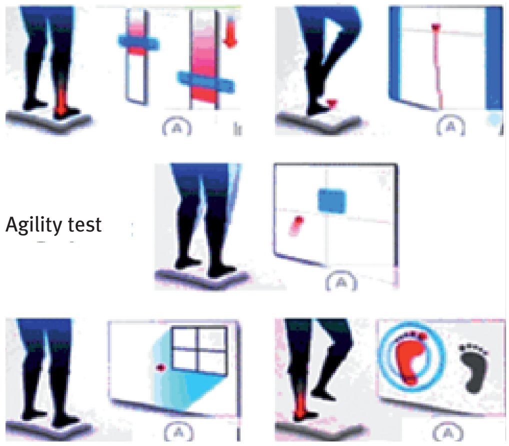
These innovative technology solutions have enabled humans to interact with a set-machine and form "new relationships" which relate to, and enhance, intellectual performances that may facilitate real life abilities. As a matter of fact, flight simulators and microsurgical techniques are based on these virtual applications. There are two other aspects that make virtual games so interesting and these are essentially: its "low cost" technology and its many possible uses. The international literature has amply demonstrated that changes in standing posture increases the risk of falling [2]. The measurement value most representative of postural sway is the center of pressure (COP), which is recorded from a force platform (FP). It provides important information [3] and is considered the gold standard measure of balance [4]. However, there are difficulties related to transportation, setup and high costs which significantly reduce its application in clinical settings [5].

The Nintendo Wii Balance Board (WBB), due to its characteristics of low cost and easy availability, could be used as a portable system for balance measurement [2, 6, 7]. The WBB, just as a FP, is equipped with four transducers which are useful in estimating the distribution of force on the lower limbs and the resultant movements in COP [8].

The WBB, used in combination with the Wii console and managed by the Wii Fit Plus (WFP) software, allows a real-time and retroactive control of body movements which are in function of the game, and the projection of real time monitoring (Figure 1). These projections have been integrated into rehabilitation programs for adolescents with cerebral palsy (PCI) [6], determining increments in participant's motivation [6, 8].

Our hypothesis is that visual-perceptual and proprioceptive-motor training, using the WBB, can significantly influence balance and produce an improvement of postural control in healthy subjects. For this reason, the goal of this study was to evaluate the effect of six training weeks (2 sessions per week) on postural stability as suggested by Pau et al [9].

FIGURE 1
EXERCISES PROJECTED ON THE MONITOR



METHODS

Participants

Twenty-five subjects: 11 males and 14 females (aged 20.28±17.24 years, height 137±31.09 cm, weight 46.76±24.00 kg) were selected for this study after the approval of the University Ethical Committee. All participants were healthy, did not present any muscular, neurological or tendon injuries, and did not report any consumption of drugs. The inclusion criteria were: no exercise and sport before and during this pilot study. After being informed about the procedures, methods, benefits and possible risks regarding the investigation, each proband read and signed an informed consent form adhering to participate in the study (signed by parents for underage children), which was in accordance with the ethical standards laid down in the Declaration of Helsinki for human experimentation [10].

Experimental set-up

All participants were tested before and after the training intervention at the location called "Fitkion" (Motor Activity Center Latina, Italy). All subjects were randomized (a Latin Square design and single blind experimental design was used) in order to execute the tests on two separate days (Pre and Post training). The relevant data were acquired between 3 p.m. and 6 p.m. under the following environmental conditions: average temperature 22°C (min 20°C, max 24°C).

Training

The visual-perceptual and proprioceptive-motor training was carried out in the period between June-July 2010 and was conducted over 6 weeks, with 2 training sessions per week (Monday and Friday); this method is in accordance with a previous study [11, 12]. All participants performed exercises in a single session (total time 15 minutes), barefooted with eyes opened and initially with their arms hanging by their side in a relaxed manner.

During the sessions, each participant underwent five tests (three minutes per single set), which were the WFP video games described below.

1. Basic Balance test

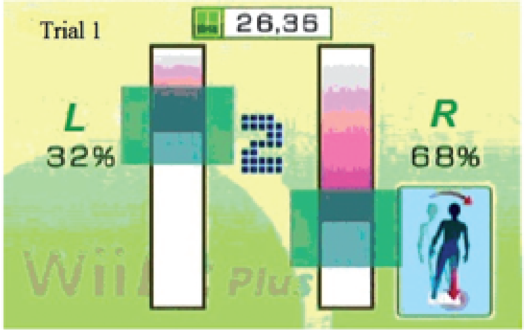
The test was performed in a standing position on the WBB (Figure 2) for 30 seconds (s) and it included 5 levels. To advance from one level to another, the user had to maintain their body-weight distribution stable for 3 s (Figure 3). The five levels provided a gradual increase in difficulty, encouraging the performer to remain stable within the projected blue stripes which were getting narrower. The maximum number of 3 s attempts carried out for balance maintenance was visualized on the monitor at the end of the test.

FIGURE 2

BASIC BALANCE TEST

Widen your feet. Try to mantain the red band within the blue area by moving your body

FIGURE 3



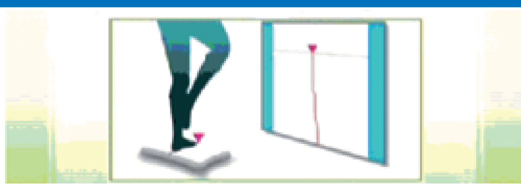
Remain within the blue area for 3 seconds

2. Single-leg Balance test

The Single-leg Balance test was carried out by single foot standing on the WBB (right and left leg balance) while watching the path created by the user him/herself on the monitor

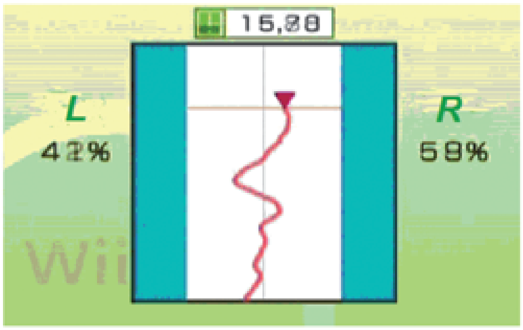
FIGURE 4

SINGLE-LEG BALANCE TEST



Place one leg at the center with the other leg up and try to mantain balance on one leg

FIGURE 5



Mantain balance on one leg

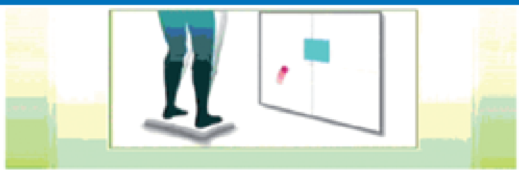
(Figure 4). The duration of this trial was 30 s and it measured the body-weight distribution, as represented by the red arrow at the center of the median line (Figure 5). The difficulty increases gradually, forcing the participant to remain stable within the white bands while the blue bands got wider. At the end of the test, a stability value ranging from 1-100% was obtained.

3. Agility test

This test lasted 30s and was executed in a standing position with participant's feet equidistant from the center of the FP support (Figure 6).

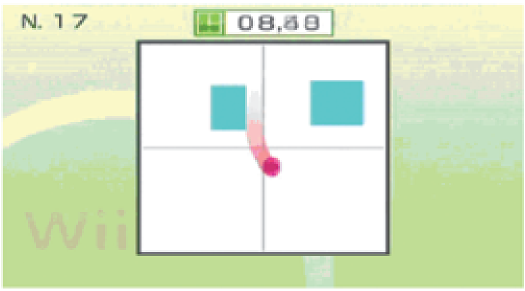
FIGURE 6

AGILITY TEST



Move your body to hit the blue areas with the red ball

FIGURE 7



Hit the blue areas with the red ball

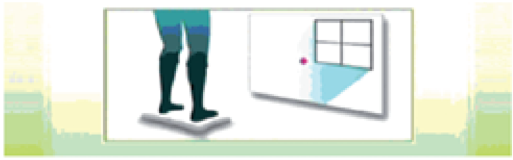
The user's body movements, made on all planes, allowed the ball to hit all the red squares on the screen (Figure 7). The trial provided a gradual increase in difficulty represented by a random distribution of blue squares on the screen, which were initially fixed and then in motion. The maximum number of squares hit, during the 30 s provided, was obtained at the end of the exercise and it represented the agility of the performer.

4. Stability test

The Stability test was performed in a standing position; the participant had to maintain

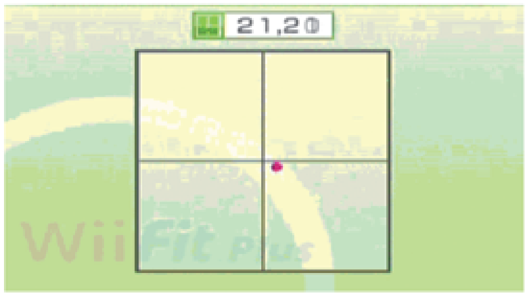
FIGURE 8

STABILITY TEST



Try to remain perfectly still for the duration of the test

FIGURE 9



Try to remain still

the maximum balance whilst holding their legs equidistant from the center of the WBB (Figure 8). The test lasted 30 s and displayed the body-weight distribution, represented by the red dot at the center of the Cartesian axis s on the screen. During the exercise, the performer watched projected images on the monitor (Figure 9). The difficulty of the exercise increased gradually, forcing the user to remain stable without being influenced by visual disturbances, such as the axes projected on the monitor that were fixed for the first 10 s, then fluctuated for the following 10 s and finally disappeared for the last 10 s. A value indicating personal stability, ranging from 1-100%, was obtained at the end of the test.

5. Motion test

The motion test required subjects to be in a standing position, with their feet equidistant from the center of the WBB (Figure 10), and they then had to march on the spot. Each step taken was represented on the monitor by a red color; the exercise was considered accomplished when 20 steps were taken. The subject watched the monitor with projected images, as in the previous exercise (Figure 11).

Values representing the percentage of total balance, and one for the different percentages

FIGURE 10

STABILITY TEST

Walk 20 paces in place, at your natural pace, with feet equidistant from the center of the WBB

FIGURE 11

Walk 20 paces in place

of load on the lower right and left limbs, were obtained at the end of the trial.

During each test, a video was produced and then played back through a graphical interface. Finally, the stabilometric signals of each trial were detected using the CoreMeter™ software (Vando Stefano, Latina, Italy) connected via Bluetooth to the WBB laying over the one connected to the Nintendo console.

Data Collection and Analysis

All data were acquired in real time using the following tools: CoreMeter™ software, Nintendo WFP, and the WBB, proprioceptive prototype "Zero".

The WBB, validated by Clark et al. as a standing balance assessment tool [2], contains four micro foil-type strain gauge transducers that are located in each of the four corners of the board with sampling rate at 100 Hz. Each transducer provides a single measure of force per sample; the data for the four sensors are transmitted to a computer via Bluetooth connection. The WBB was monitored with the CoreMeter™ program which measured the body's center of gravity, allowing an immediate graphical and numerical representation of the performed exercise.

The CoreMeter™ software enables the measurement of the COP's length (Path) and speed, number of repetitions, frequency and percentages of stability, and balance of the loads exerted on the lower extremities. The medial-lateral coordinate of the COP was represented on the horizontal axis (x) while the anterior-posterior coordinate was represented on the y axis.

The proprioceptive prototype, called "Zero" (Figure 12), consisted of two overlapping WBB: the underlying portion was connected to the Nintendo Wii, while the one above was controlled by a Personal Computer (PC). The particular geometry and assembly characteristics of the device allowed for a gradual management of instability during movements in correspondence of all planes.

The prototype used in this study (Figure 13) was composed of two lapping "Zero" devices (in PVC and polyurethane) joined together with elastic cords and separated by an air chamber.

FIGURE 12

THE "ZERO" DEVICE

FIGURE 13

THE PROTOTYPE

The first "Zero" was in contact with the ground (weight 9 kg, height 13 cm at the center and 8 at the extremity with 72 cm of diameter). The second Zero (weight 12 kg, height 17 cm at the center and 12 at the extremity with diameter of 72 cm) was reversed on a ball cushion (Dynair® System) and had a diameter of 33 cm, which was supported by the first Zero so as to contain two WBB. This prototype was calibrated to allow a resolution of 1 $mm \cdot kg^{-1}$ through the measurement, in centimeters, of the vertical displacement performed by a needle positioned on the upper base of the device when a load was placed on one side of the WBB.

Statistical analysis

Descriptive statistics (median, inter-quartile range, means and standard deviation) were calculated for quantitative variables and frequencies were generated for qualitative variables. To test the repeatability of the measures, we performed an Intra-class Correlation Coefficient (ICC) between length and velocity of the COP before starting this study, as a standard quality assessment procedure. Univariate analysis was conducted with the Wilcoxon signed-rank test for two dependent samples or for paired data (significance level set at $p<0.05$). The statistical software used for data analysis was SPSS 19.0 for Windows.

RESULTS

The sample was composed of twenty-five subjects with a mean age of 20.28 years (SD=17.5), of which 44% were male and 56% were female. Participants <20 years old accounted for most of the sample (68%), followed by those >40 years (20%), whilst those 20-40 years old represented only 12% of the sample. The analysis of data recorded with the Nintendo Wii (Table 1) shows statistically significant differences ($p<0.001$) between the initial and final stages of the five tests (Basic Balance, Single- leg Balance, Agility, Stability and Motion).

The variables studied with the WFP increased at the end of the training program (Table 1) compared to baseline conditions, reflecting improvements in performance. This result was confirmed by the WBB data which decreased both in length (LC) and velocity (VC) of the COP compared to baseline. In addition, LC and VC showed highly reliable data, with a strong ICC as a standard quality assessment procedure for LC (range 0.89-0.97) and VC (range 0.88-0.97).

Similarly, data monitored with the CoreMeter™ software (Table 2) for the above mentioned tests, highlighted significant differences for all the parameters under consideration. In particular, the values of Path [length of the stabilometric ball (mm)], V Medium [center of gravity average displacement speed (mm/s)] and Sigma V [standard deviation of the center of gravity displacement speed ($mm \cdot s^{-1}$-variance)] were reduced in all the tests carried out ($p<0.001$ for all tests; $p=0.02$ Sigma V in the Basic Balance test). The only exception was the Agility test, which showed a substantial increase in all parameters evaluated ($p<0.001$).

Regarding age, participants in the <20 years age group presented significant variations in all tests recorded with the Nintendo Wii ($p<0.001$ for Basic Balance; $p<0.001$ for other tests) and in all trials analyzed with the CoreMeter™ software, except for Sigma V in the Basic Balance test ($p=0.11$).

The participants between 20-40 years old had no statistically significant differences for the tests analyzed with the Nintendo Wii ($p=0.11$) nor for those analyzed with the CoreMeter™ software. Subjects aged >40 years presented significant variations in all tests monitored with the Nintendo Wii ($p=0.03$ for Basic Balance; $p=0.04$ for other tests). Relative to data collected with CoreMeter™, significant changes were observed in the Left leg Balance test ($p=0.04$ for Path and V Medium), and in the Right leg Balance and Agility tests ($p=0.04$). In all other exercises, the power effect was not found.

There were no differences between genders for the data reported in Table 1. In fact, both sexes show significant variation for all tests monitored with the Nintendo Wii. Even for the data analyzed with the CoreMeter™ software, differences between the sexes were not found: both genders presented significant p-value for all trials, except for the Sigma V in the Basic Balance test ($p=0.11$).

DISCUSSION

The present pilot study evaluates postural changes and balance in twenty-five healthy individuals involved in a program including

TABLE 1

ANALYSIS OF DATA RECORDED WITH THE NINTENDO WII CONSOLE

TEST	NINTENDO WII CONSOLE		P-VALUE[a]
	START MEDIAN (IQR)	END MEDIAN (IQR)	
Basic Balance Number of valid trials in 30 sec	3 (1)	4 (1)	<0.001*
Single-leg Balance % stability in 30 sec:			
- Left leg	55 (27)	71 (16)	<0.001*
- Right leg	48 (30)	71 (14)	<0.001*
Agility Number of squares hit in 30 sec	14 (3)	18 (2.5)	<0.001*
Stability % stability in 30 sec	21 (18)	35 (18)	<0.001*
Motion % stability in 30 sec	41 (42)	71 (33)	<0.001*

[a] p-value Wilcoxon signed-rank test; *p<0.05; IQR=inter-quartile range; Start-End: beginning and end of the training program

interactive and recreational activities. The CoreMeter™ software was used to analyze the COP trajectory (stabilometric ball). In particular, the length (Path), the displacement speed, the shape and the position of the stabilometric ball compared to the center of the Cartesian axes were calculated.

The study highlights some differences regarding the participants' ages. Particularly, younger subjects (<20 years) presented important variations at the end of the training respect to baseline conditions. These subjects reduced the length and the displacement speed to achieve better balance. Practically, they represent the age group with the best response to dynamic stimuli. This result could be due to a greater agility or flexibility related to their young age.

Conversely, the 20-40 years old participants showed minor variations for all data analyzed, while in the Stability test they didn't present any effect size. These results may indicate a lesser adaptability or learning capacity of these subjects, and it may be linked to a sedentary lifestyle. These findings are in disagreement with Hanneton and Varenne (2009) [13], according to which the performance of 23-36 years old participants improved significantly in all exercises with WBB. Minor improvements observed in that study for 60 year olds were perhaps due to a difficulty in understanding test instructions.

In older subjects (>40 years), the effect was similar to those of younger individuals in this sample. The elderly performers demonstrated major improvements in Single-leg Balance and Agility tests.

Encouraging results, indicating improvements of all performers - especially the younger ones, emerged from the present investigation. Above all, the stabilometric ball length (Path), the center of gravity average displacement speed (V Medium) and its standard deviation (Sigma V) tended to reduce in all tests, except in the Agility test. These data underline the participants' tendency to search for equilibrium under dynamic conditions, greater motor agility and good learning skills.

There are several studies in the literature focusing on postural improvements in persons with disabilities [6, 14-16] and in elderly subjects [7, 17, 18] using the WBB system as a tool for the study of posture. Those studies confirm improvements in postural control and motivation of participants.

TABLE 2

ANALYSIS OF DATA MONITORED WITH COREMETER™ SOFTWARE

TEST	COREMETER™ SOFTWARE START MEDIAN (IQR)	COREMETER™ SOFTWARE END MEDIAN (IQR)	P-VALUE[a]
Basic Balance			
Path	246.44 (122.72)	196.73 (122.67)	<0.001*
V Medium	8.22 (3.91)	7.56 (3.74)	0.001*
Sigma V	12.17 (8.32)	11.31 (7.96)	0.02*
Left leg Balance			
Path	310.19 (190.61)	221.45 (159.78)	<0.001*
V Medium	10.85 (8.43)	7.38 (5.33)	<0.001*
Sigma V	14.22 (12.59)	10.23 (9.96)	<0.001*
Right leg Balance			
Path	312.50 (225.90)	217.15 (181.51)	<0.001*
V Medium	9.93 (8.83)	7.29 (5.91)	<0.001*
Sigma V	13.31 (11.60)	10.23 (10.12)	<0.001*
Agility			
Path	950.87 (844.39)	1507.70 (999.46)	<0.001*
V Medium	31.71 (31.12)	50.27 (35.53)	<0.001*
Sigma V	37.59 (46.42)	57.86 (44.90)	<0.001*
Stability			
Path	170.87 (122.47)	152.69 (88.93)	<0.001*
V Medium	5.70 (4.08)	5.09 (2.97)	<0.001*
Sigma V	9.16 (8.73)	7.33 (6.79)	<0.001*
Motion			
Path	815.19 (190.03)	717.46 (133.61)	<0.001*
V Medium	45.58 (17.86)	38.85 (15.52)	<0.001*
Sigma V	68.08 (38.31)	57.45 (29.71)	<0.001*

[a]p-value Wilcoxon signed-rank test; *p<0.05; IQR=inter-quartile range; Start-End: beginning and end of the training program; Path: stabilometric ball length (mm); V Medium: center of gravity average displacement speed (mm·s^{-1}); Sigma V: standard deviation of the center of gravity displacement speed (mm·s^{-1}-Variance)

CONCLUSIONS

The use of proprioceptive devices with the possibility to grade the level of instability during visual perceptual and interactive training, such as a FP connected to a PC controlled by suitable software, gives feedback on the performed movement with important information relative to one's posture control. This virtual training program allows us to develop a structuring strategy for improving motor control, as well as to plan and execute precise and well-targeted trajectories. The present pilot study underlines the effectiveness of visual-perceptual-proprioceptive training with playful motor aspects that involve the use of unstable tools that help to improve:

- Posture and balance control;
- Postural control in anterior-posterior and medial-lateral fluctuations;
- Learning process in the execution of motor tasks;
- The subjects' skills in maintaining balance while transiting from static to dynamic state and vice versa;
- The response of proprioceptive feedback

mechanisms to contrast balance loss faster;
- The kinaesthetic sensations (awareness of movement).

A limitation of the study is certainly the low sample size (N=25) and that there was a substantial heterogeneity in participants' age (5<55 years); moreover, individuals <20 years old are highly represented compared to other age groups. Hence, the sample is not a perfect representation of the general population. This study requires an implementation of the sample with more individuals of similar age and a control group carrying out the same exercises using solely visual and voice support.

The intent of this investigation was to offer a contribution to Motor Behavior research by monitoring subjects engaged in physical activities aimed at improving and optimizing their athletic performance. The results of the present study could represent an input for the application of new methodologies, which include the use of reliable and low cost technological devices that quantify physical activities.

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