Development of a Hardware/Software System for Proprioception Exergaming

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Abstract

Physical equilibrium and balance are key factors for human activities. Training for improving proprioception employ new, effective methodologies and tools. However, such tools are sometimes boring and difficult to use properly in achieving the given training goals. Exergaming, the combination of physical exercise and video-gaming using smart tools, may help to overcome these issues by offering enjoyment and motivation. However, the literature lacks papers investigating how to integrate tools for proprioception training into a serious game combining effectiveness and enjoyment. In this paper, we focus on the Balance Board (BB), a device used in gyms and in several health-related applications, and present an exergaming system for proprioception training. The system includes a BB, which was instrumented to act as a motion controller for an ad-hoc developed, simple 3D video game. The system aims to provide enjoyable training, boosting equilibrium exercising through the simulation of downhill skiing. We validated the score computation and tested the efficacy of the system in a user test with 40 healthy participants, in ecological settings. The evaluation concerned user performance and a game experience questionnaire. The results, deduced through mapping users' performance to their balance capacity, showed statistically significant improvement in players' ability to use the BB. Users also reported a positive gameplay experience.

Keywords: *Motion Controller, Balance Board, Video Game, Exergame, Balance Training;*

1 Introduction

Proprioception - the sense of the relative position of one's own parts of the body and strength of effort being employed in movement [5] - is particularly important for equilibrium, and can be trained through various disciplines. The Balance Board (BB) [1], a common tool in gyms and sports lounges, is used for proprioception training. The BB is ideal for therapeutic exercises following an ankle injury, which is common among athletes, particularly in skiing, snowboarding, tennis, and golf. Furthermore, balance training is useful also for healthy people, in everyday activities. With enough equilibrium training time, the brain is able to react to sensations more efficiently. According to [6], training with the BB resulted in significant increase in balance performance and strength of the muscles.

The BB is one of the tools used by physiotherapists to rehabilitate ankle and knee injuries, especially among athletes. More in general, full and functional movement, in fact, is considered at the heart of health [2], and serious games (SGs) [3] are increasingly being incorporated in physical exercise activities [4].

Maintaining balance on a BB is a challenge due to its exquisite design. As shown in Figure 1, the board has a rigid surface sitting on a rounded dome underneath. In order to keep it steady, the users must employ their proprioceptive senses while adjusting their bodies' center of gravity along the board's center. Practicing with the BB is quite a boring exercise, which could lead to discouragement. Since video games can add fun, we thought of developing an exergaming platform integrating a BB with the aim of providing an enjoyable balance exercise. To the best of our knowledge, this is one of the very first attempts to enrich a physical exercise device with sensing, computing and communication capabilities in view of an integration in an SG.

The literature, in fact, lacks papers investigating how to integrate such devices into a SG combining effectiveness and enjoyment. In this paper, we thus address three main research questions (RQs) about trying to improve the user experience in balance and proprioception.

1- Can a SG be designed to support a proper and effective use of a typical proprioception tool such as a BB? What are the main fundamental features/mechanics of such a game?

2- Is there an improvement in using the BB through the SG?

3- Is the overall user experience positive?

In order to answer these questions, we developed an experimental hardware and software system aimed at supporting an effective and enjoyable use of the BB, as similar systems on the market lacking either the serious or the entertainment aspects. The system consists of a device extracting the dynamic from the BB and of a simple 3D serious game giving to the player the stimulus for a proper use of the tool. We then designed and performed an experiment in ecological settings, addressing the three RQs stated above. In the experiment, we tested user performance over consecutive trials and collected feedback through a questionnaire.

The remainder of the paper is structured as follows. Related work is presented in section 2. Section 3 describes the implementation of the system starting with a listing and detailing of the involved hardware and connections then describing a ski video game featuring giant slalom. In section 4, we go through the testing phase. Section 5 presents and discusses the results, while conclusions and future work are provided in section 6.

2 State-of-the-Art

Balance-oriented applications and exergames have been developed and proposed in various contexts [7], especially as commercial, off-the-shelf games based on inertial sensors [8]. A pilot feasibility study was conducted in two Dutch rehabilitation centers [9] to compare the game experience of a self-developed exergame for balance problems to a commercially available balance game. The study featured a gryphon riding video game tracked by a kinetic device. A commercially available balance game called River Rush of kinetic adventures was used for comparison. The results of the study indicated the great challenge to develop a game that is interesting to play while focusing on rehabilitation training. The study in [10] previews an investigation into the possibility of embedding clinically relevant assessments of balance within a bespoke Wii-Balance Board exergame. Testing sessions of exer-gameplay included twenty-seven adults. The exergame is based on the game known as PONG, where players use their balance (moving along the anterior-posterior plane) to move a paddle to intercept a ball. The study found that it is possible to objectively evaluate clinically relevant measures of functional balance during exer-gameplay. These findings were based on the results obtained within-game that were evaluated as correlating with relevant clinical measures of functional balance. In a related context, a home-based rehabilitation for balance training via a web-application was presented in [7], while an exertion game called SilverBalance was presented in [11]. SilverBalance is an exergame that consists of two balance tasks (sitting and standing) for the elderly, both using the Nintendo Wii Balance Board. The game contains obstacles that need avoiding. [12] proposed a system that uses the metaphor of a game contributing to the motivation and engagement of patients during postural instability treatment. The results of the system, based on posturographic assessment, showed consistent estimatives for stabilometric measurements. Motion capture can be acquired in different forms other than sensing boards (e.g., [13] [14]). In [15], a low-cost depth-sensing camera was used to provide full body tracking on the PC. The tracking is used to control full body animated virtual characters in commercial video games. The aim was to develop an interactive game-based rehabilitation tool for balance exercises in adults. The game was developed to train reaching and weight shift using the Microsoft Kinect sensor. The assessment showed the potential use of this game as a rehabilitation tool. The incorporation of stepping movements into the gameplay of a VR based exergame is presented in [16]. It envisages that balance training through recovery stepping movements in all directions may reduce fall risk in older adults. The use of the inertial sensor, it was concluded, can accurately detect steps being performed more than the limb movement detection that camera-based systems offer. The above presented commercial games are excellent examples of games targeting balance. However, they do not concern the use of any specific therapeutic device.

Systems [9] through [16] - already mentioned - describe a wide range of related applications. Some lacked a motivational/engaging component while others lacked enjoyment in gameplay. Some relied on commercial and expensive technologies and others focused deeply on therapeutic exercise to an extent that makes it unsuited to healthy people. Sensamove is a high-level exergame, supplementing the analysis and tracking of the user’s exercise on a Balance board used in [17] and [18]. The software, which is able to sensitively record the users’ movements, gives information about body stability, response time and potential imbalances. Its cost starts from 400 US dollars. On the other hand, our system relies on open source hardware (Arduino) and free software (Unity3D).

An important aspect of SG design is the balance between competition and collaboration. [19] examined the role of competitive versus cooperative gameplay in an exergame condition. Forty-five youth people followed a 10-week exergame training intervention, grouped into three condition groups: competitive exergame condition, cooperative exergame condition, and a no-play control group. The results found that competitive exergame condition improved the youth’s executive function skills more than the cooperative and no-play exergame conditions.

Concerning training effectiveness of exergames, [20] investigated three games with the goal to determine if exergaming can elicit a training response. Male and female college students were recruited to participate in game testing exercises with each wearing a metabolic equipment during gameplay. The results showed that participants, on average, could reach the recommended exercise intensity. In a similar study, [21], the emphasis is placed on computerized physical exercise. The goal of the authors was to identify its positive effects on the physical and mental capacity as well as the quality of life of participants. The considered improvements concern two cases of physical exercise protocols: balance and aerobic. An intervention was conducted with twenty-two participants on a ten-week schedule. The physical assessment results showed improvement in body strength, balance and aerobic capacity, shoulder flexibility, and fall prevention capacity. A neuropsychological examination showed improvements as well. The research in [22] describes a set of personalized exergames that integrate vital parameters of users into the gameplay in order to support training and motivation for physical activity. The video games had no substantial educational level. Each game uses a different sensory input as a controller. The paper concluded that this approach showed benefits in technical feasibility studies and group tests and that the game had a direct influence on player behavior.

Exergames are typically validated by analyzing their effects, especially on physical factors directly related to the exercise type [23]. A survey performed on 15 quantitative exergame studies to define a general set of elements that make exergames effective from a physical standpoint was presented in [24]. In addition, [25] found, through selecting and analyzing developed gamified systems, that there exists a tendency to develop low-cost solutions for in-home exercising with various games [8] [26]. In [27], the methodology was to use data collected during SG exercises for later analysis in order to monitor the long-term evolution of patients.

Summarizing, the literature review has shown that various systems exist to support balance and equilibrium training. The majority of such systems are based on commercial off-the-shelf tools and services. Thus, the literature shows that existing systems provide solutions to certain balance-driven exercises, and it is time to start investigating how to integrate physical exercise devices in compelling SGs combining health effectiveness and enjoyment, at reasonable costs. This motivated our choice for designing a specific, low-cost hardware and software system, also integrating some of the features and mechanics used by the presented systems, such as the use of IMUs, competitiveness in gameplay, data analysis techniques, etc.

3 Implementation

In order to test an SG able to support a proper use of the BB, we developed hardware and software modules and related integration tools for the BB. Hardware components are sensory and processing units acting as PC peripherals. Such components constitute internet of things (IoT) front-end measuring devices of user interaction, which is fed into the PC. The PC hosts a software module showing a skiing simulation video game, representing the feedback from the system to the user interaction and performance. The SG encapsulates fun gameplay in a rule-based game scenario. A software integration module was programmed to serve as a connection manager between the video game and its hardware controllers. This connection manager is responsible for a reliable and compatible transmission of measurements from motion controllers to the SG.

3.1 Hardware and Devices

Inertial measurement units (IMUs) [28], which are the cornerstone of our exergame, are embedded units that compose motion sensor circuits. When connected to a microcontroller device, usually in serial I2C connection, IMUs can provide instant raw inertial measurements estimations in the form of acceleration, angular velocity, and magnetic field direction. The resulting hardware module is a motion-sensing module. Such module is programmed to share its measurements through the communication with other modules and computers in wired and wireless modes. We used USB connection from the motion-sensing module to the PC since almost all microcontrollers support USB and it is a more reliable connection than wireless. The motion-sensing module can be attached to an object and along one of its surfaces to capture measurements of its rotations. Such measurements cannot be game-ready by default. So a software tool is needed to provide the support for integration.

Open-source microcontrollers are plenty, and we designed our system to be adaptable to all. To prove that, we used two different types of microcontroller boards: Arduino [29] and STM32 [30]. We connected the Arduino to a SparkFun 9DoF IMU Breakout - LSM9DS1 motion sensor [31], while we benefited from STM32's own MEMS shield, the X-NUCLEO-IKS01A1 [30] shown in Figure 1, for simplicity. The Arduino was programmed in C using the Arduino IDE. For the STM32, we chose to code with Arm MBED [32] online compiler also in C language. Eventually, both firmwares have the same functionality: read raw inertial data from sensors, compute the rotation angles, filter the computations through a Kalman-based algorithm, then send the estimated information serially through USB to the PC. Repeat that every five milliseconds and the control should be sturdy and smooth for the character control in the video game. The use of two different microcontrollers is intended so the system has cross-platform support. Both microcontrollers transmit in a standard format that is programmed within the firmware despite each one being connected to a different IMU type.

We attached the microcontrollers, each one connected to its suitable IMU sensor, to Balance Boards (Figure 1). We noticed that it does not differ where to attach the microcontroller on the surface of the Balance Board; whether it is centered, in front or at the rear has no effect on the measurements [33]. Multiple Balance Boards can host the same or different microcontroller types and they would be able to perform all the same.

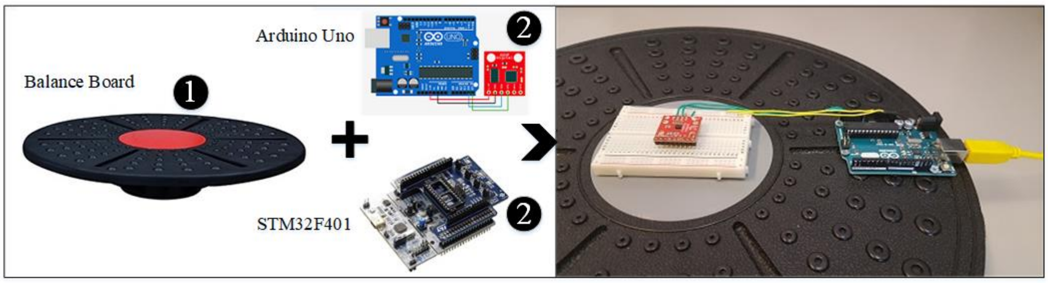

Figure 1. *Hardware constituting the motion controller*

3.2 Development of the Serious Video Game

A video game was designed to act as an enjoyable graphical user interface for the system. The main goal is to stimulate the users to a proper use of the BB and provide immediate feedback about their performance. The video game should be easy to understand and play, in order to avoid any barrier for any kind of user and to allow everyone to have a positive experience using the BB. Since the BB is mainly related to equilibrium skills, we chose the metaphor of a sports activity such as skiing, which is deeply related to equilibrium.

The video game scenario resembles a Giant Slalom skiing and snowboarding discipline. The Giant Slalom is an official Olympic Alpine skiing sport. It involves skiing between sets of poles spaced at a certain distance from each other.

We designed the video game in Unity3D [34] to simulate a realistic session of Giant Slalom, taking into consideration the slope of the downhill, the distances between poles, and sharpness of the course curves. The player’s goal in the game is to complete the skiing course from the launching pad to the finishing line in the least duration possible while maintaining the area within every adjacent pair of poles. Yet, the video game was designed with more tolerating rules than the real Giant Slalom rules, since establishing the same rules as in reality would negatively affect the encouragement of the users [35]. In particular, skipping a pole implies a penalty, not the end of the race for a user, in order to avoid frustration.

The video game, shown in Figure 2, features realistic character animations. To achieve that, we had to analyze the movements of real skiing professionals, through repetitive edit-and-compare, until mimicking to the best extent those movements in the ski character’s movements in the video game. Also adding to the realistic factor, the physics and dynamics we employed in the character motion and its interaction with the environment constituting of: speed, acceleration, friction and resistance, gravity, body posture, snow stiffness and curving strength.

Regarding terrain design, we did a map grab via terrain.party of the Italian Alps, and then imported it into our Unity scene, thus adding a realistic view to the landscape.

The game supports two types of input control: the keyboard and the Balance Board. The keyboard is a universal game controller and was supported as a control measure procedure, while the game should be designed so that all its difficulty (that should be rewarded by the score) relies on properly controlling the BB, which is the SG's actual training goal.

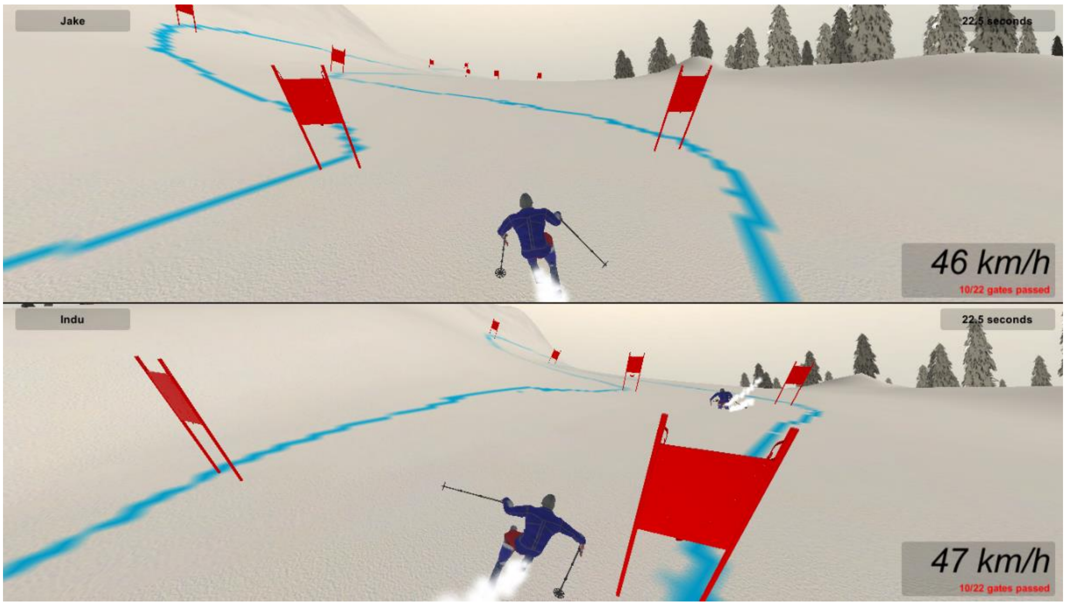

Figure 2. *The split-screen mode in Giant Slalom video game*

The Balance Board can be selected as the sole controller following a simple procedure. The procedure executed by the integration software is a three-step motion-control integration process. The first step is automatic port detection for connected motion-sensing microcontrollers. Step two is the creation of a menu adder listing those microcontrollers. Finally, step three is motion controller assignment to game characters. Figure 3 shows the menu generated by the integration tool. The keyboard is disconnected from the game's character control once the motion controller is set instead. At this stage, the character is controlled by the Balance Board manipulation only. That is, the video game is receiving continuous inertial measurements from the controllers attached to the BBs. The measurements are thus transformed to become control parameters in the SG before being applied to the ski character.

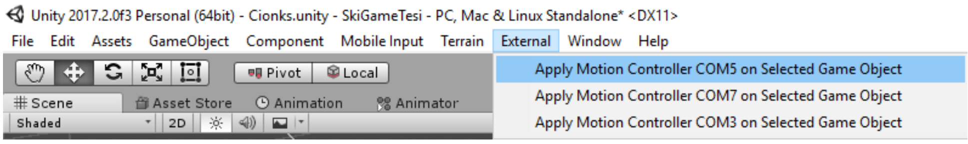

Figure 3. *Motion Controller's auto-generated menu tab in Unity*

The official Giant Slalom dictates that each competitor goes alone on the skiing course. Our game supports that as well, recording the scores of every session given that the player completes the course successfully to the finish line. Competitiveness is an important factor in immersive gameplay. For that reason, we introduced live duels so players can compete at the same time and on the same course using two Balance Boards. Since we have the ability to connect multiple motion-sensing controllers, the game can be switched into the split-screen mode. A key, basic mechanic for any properly designed SG is the score that, on the one hand, should stimulate competition (also self-competition) and enjoyment, on the other hand, it should reflect the instructional goals of the SG. This fundamental mechanic may be altered or complemented by other mechanics as well, in case of need (e.g. to increase fun and a chance effect).

Moving swiftly and smoothly between poles is the result of a good and precise balance control on the Balance Board. Eventually, the video game aims to enhance the player's ability to use the Balance Board. At the end of a game session, the score of the finishing player is computed considering the standard factors in a Giant Slalom: time and poles crossed legitimately. We use the following equation to compute the score:

$$s = 50 * (e^{(p-t)*r} + n/N) \quad (1)$$

In equation (1), s denotes the session score. The Symbol p corresponds to the perfect session timing - the timing of a session played by a game bot. While t is the final session timing, r is time-to-score dependency ratio. This ratio specifies how much the score is affected by the timing deficit at the expanse of pole skipping penalty. For a score dependently balanced on both time deficit and pole skipping, we set it at 0.14 with respect to the observations of tens of consecutive simulations. The number of gates legitimately crossed is represented by n, while N is the total number of gates in the Giant Slalom game. The score was tailored to reflect on the players' balance skills the most. The player's balance skill using the Balance Board will directly affect smooth skiing between poles in the video game and such skiing attitude will affect the time for ski course completion as well as the legitimacy of poles crossing. Thus, the score of equation (1) was designed as a reasonable candidate, that we later validated in the experiment by matching the relationship between hardware and software components of the presented exergame.

4 Experimental Set-up

A user test was set up to prove the impact of the developed exergame system, with the specific goal of answering the three RQs stated in the introduction. The game experience is mainly summed by enjoyment and immersion factors, which are the main attraction that entices users towards playing the game [36]. Nonetheless, several other factors and parameters contribute to game experience such as the environment (sounds and graphics) and control, as well as frustration that is a negatively worded factor.

In user testing, we had 50 participants taking trials in the game. Ten of them did not comply with the testing methodology – through insubordinate behavior, thus we disregarded their experiments. The remaining 40 participants (23 males and 17 females), were mainly university students aged between 19 and 25 with an average age of 23.6 years old. All participants were in good physical, functional and mental state – corresponding to our training target. The experiment took place in a spacious living room (with dimensions of 6.0 m x 7.0 m x 3 m) in a residential apartment of one of the authors. We chose an apartment's living room as it represents the expected playing environment quite faithfully. In addition, a residential location is the intended exercising place to use our system. The video game was executed on an Asus F555LP-XX087H notebook with a dual display, one is the notebook's 15.6" screen and the other is a projector onto the wall. The projector set-up is optional, as it provides better user view of the SG.

The experiments were designed as follows. Participants were provided a 5-minute overview of the game (idea, how to play, etc.), and then had a short timeframe of other 5 minutes to freely explore the game interface, settings, and connections. After this exploratory period, each participant started an eight-trial solo session. The session lasted around 40 minutes with each trial taking approximately 5 minutes. In a single trial, the player had to ski along the trail from the starting line to the arrival line, once using the Balance Board and once using the keyboard. After the solo trials, we randomly selected couples of participants and asked them to compete in a duel session using the Balance Boards. Similar to the solo mode, we recorded 8 trials in each duel session. The reason for choosing 8 trials is to have a constant and ordered trial span. Moreover, the session of 8 trials provided enough progressive trials for a training effect to take place. We also considered the participant's involvement time in the experiment as to be within an hour for each mode (solo or duel). We did not have a specific order for the participants, we agreed with all participants to come on their free and most convenient time.

Figure 4. *Two participants testing the exergame in competitive mode.*

Figure 4 shows participants playing Giant Slalom ski game in ‘duel’ mode with the motion-control Balance Boards. Figure 2 is an in-game screenshot of their duel. Scores from both playing modes were recorded into a dataset.

Table1. *List of Questionnaire’s Items*

	Items
1	I enjoyed playing the game
2	I was frustrated at the end of the game
3	I was frustrated whilst playing the game
4	I liked the game
5	I would play this game again
6	I was in control of the game
7	The controllers responded as I expected
8	I remember the actions the controllers performed
9	The graphics were appropriate for the type of game
10	The sound effects of the game were appropriate
11	I did not like the music of the game *
12	The graphics of the game were related to the scenario
13	The graphics and sound effects of the game were related
14	The sound of the game affected the way I was playing
15	I understood the rules of the game
16	The game was challenging
17	The scenario of the game was interesting
Additional	I think the game has training (balance education) potential

**** Denotes items that are negatively worded.***

We agreed with the participants on the anonymity of the experiments, thus no real names were used. Furthermore, we had signed consents from the participants to use the multimedia and in-game recordings in which they were involved.

Survey-based evaluation method in testing is a recommended approach to score the user experience [37]. We preferred a customized version of Core Elements of the Gaming Experience Questionnaire (CEGEQ) [38] over more recent scales (e.g., [40]) since such scales targeted more abstract game modes, and thus contained several core items that are not considered in our current investigation, like mastery and curiosity items. After the participants finished the experiment, we administered a questionnaire of 17 items to assess the gaming experience in compliance with the CEGEQ. The participant would choose an answer based on a 5-point Likert scale for each item (1 = strongly disagree; 2 = disagree; 3 = neutral (Neither agree nor disagree); 4 = agree; 5 = strongly agree). The items used in our questionnaire are shown in Table 1. We also asked the participants to rate their own skill levels in skiing and skating as well as their thoughts on the pedagogical potential of the video game. The questionnaire's 17 items concern the following 5 scales: Enjoyment (items 1, 4, and 5), Frustration (2-3), Environment (6-8), Gameplay (9-14), and Control (15-17).The test's data processing was done using the statistical computing environment R [39].

5 Results and discussion

According to our design, the support to a proper use of the BB was associated with a system integrating an inertial system embedded on the BB and a Giant Slalom skiing video game displayed on a PC. The game was designed to reflect the player's abilities in balance control, and session scores were used to assess the user performance. Were these design choices suited to positively answer RQ1? RQ1 included the following two sub-questions. Can a serious game be designed to support a proper and effective use of a BB? What are the main fundamental features/mechanics of such a game?

To answer this question, we cross-examined the game scores using the Balance Board with the participants' skill levels (averaged between skiing and skating skills), in order to check whether the designed in-game score was able to reflect the real-world user equilibrium abilities. The skill level was self-assessed by the participants. We asked for the skiing and skating skills rather than explicitly for the balance skill because skiing and skating require balance capacity, and a participant finds it harder to assess self's balance capacity out of a context. Thus, this skiing/skating skill could be regarded as skill in maintaining equilibrium.

Results, recorded in solo mode, (0.738 Pearson correlation coefficient, significant at 0.01 level, two-tailed) show a certain proportionality between the participant's balance skills and their scores in the skiing video game, which seems to indicate that the video game scores do reflect the participants' equilibrium skill levels quite well. In contrast, the almost null correlation (0.01 Pearson correlation coefficient) obtained while using the keyboard as input tool indicates a tight correspondence between the scoring mechanism and the balance skill. We thus argue that our design choice of exploiting the context of a skiing sports activity, controlled by an inertial sensor embedded in the BB and with the score computed as described in subsection 3.2, are fundamental basics that match and solicit the abilities targeted by a BB. To completely answer RQ1, we also need to check whether the developed SG was able to support an effective and enjoyable use of the BB, which is addressed in the following experiment analysis steps.

At a first glance, the scores recorded from trials using the motion-controller generally showed improvement from each trial to the next one, while the results with the keyboard input look stable and high. This thus seems to indicate that the keyboard could be used as the reference for our tests.

In further data analysis, we used keyboard-controlled trial scores as a control measure. We chose the keyboard to be our reference because it is the universal game controller of PC video games and the participants were all familiar with it. Figure 5 shows the average scores of all participants in each trial using the keyboard and using the motion controller. These are the raw data for addressing RQ2: is there an improvement in using the system through the SG?

This also confirms our design choice that, ideally, the game difficulty should be due to its training goal, which is the proper control of the BB. The game itself was easy to understand and immediate to use (so, it did not pose a cognitive/ behavioral overhead), and the player performance improvement can only be attributed to a better use of the BB controller, which is our actual instructional goal. Figure 5 shows that, beyond the 6th trial, the BB average scores tend to converge to a linear saturation level.

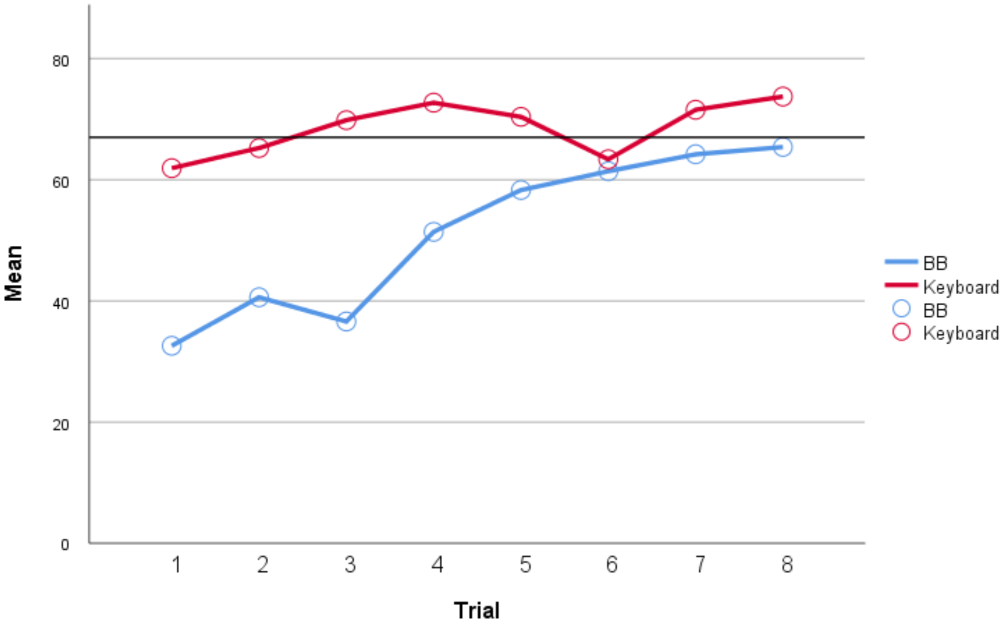

Figure 5. *Trial averages of the scores using the two Controller types*

A paired-sample t-test on keyboard and motion controller records was performed to check for the difference between the two halves of the eight trials for each input type. We divided the sessions into two halves in order to keep into account possible variations between close-by sessions. Normality was tested through a Shapiro-Wilk test, which gave p-values of 0.482 and 0.725 for BB and Keyboard data scores respectively. Thus, we can reject the alternative hypothesis and conclude that the data set comes from a normal distribution.

Table2. *Paired-sample t-test mean values*

		Mean	Std. Deviation	Significance (p-value)
Pair 1 ***Keyboard***	**Trials 1 to 4**	67.9200	4.07874	0.198
	Trials 5 to 8	70.2525	3.54306	
Pair 2 ***Motion controller***	**Trials 1 to 4**	38.3000	8.08868	0.002
	Trials 5 to 8	59.3250	4.35230	

The results, listed in table 1, show statistical significance in pair 2 (motion controller) but not in pair 1 (keyboard). This indicates that user performance using the keyboard as input device was stable across the sessions, while there was a positive improvement effect with the BB-embedded motion controller.

Combing the Pearson correlation values obtained between the scores and balance skills (indicating that scores reflect quite well the participants' equilibrium skill levels) and findings from Figure 5 seems to suggest an improvement in player's balance capacity throughout the trials. Adding to that the feedback from the participants on the balance learning capacity (last row of Table 3), we get a reasonable basis to support a positive answer to RQ2.

RQ3 concerned the overall user experience, which we assessed through the questionnaire's five scales presented in the previous section.

For each scale, Tab. 3 reports the computed mean and standard deviation values. To validate the internal consistency of the scales, a reliability analysis was performed, with a confidence interval of 95%. The obtained Cronbach's Alpha attribute values, together with their interpretation, are reported in Tab. 3 as well.

Table 3. *Outcome Measures*

Scale	Mean	Std. deviation	Cronbach 's Alpha	Scale's internal consistency
Enjoyment	3.804	0.442	0.811	Good
Frustration	2.438	0.54	0.453	Unacceptable
Control	3.902	0.434	0.79	Acceptable
Environment	2.794	1.244	0.636	Questionable
Gameplay	4.059	0.412	0.627	Questionable
Balance training	3.765	1.059	-	-

Based on the internal consistency analysis, we disregard the frustration scale due to its low value. On the other hand, the Enjoyment, Control, Balance train and Game-Play scales all gave above the average means. Interestingly, the highest assessment was for gameplay, probably suggesting that the overall experience was positive even beyond the single factors. The low mean of the game environment factor gives us feedback that sounds and graphics in our video game design could be improved. The fact that environment and not, for instance, control was the main weakness of our design suggests that the BB-based exergaming experience could have even greater benefits. This feedback confirms the effectiveness of the designed combination of hardware and software for the exergame goal, thus allowing a positive response to Q3, and completing the answer to Q1.

6 Conclusion and future work

Balance and proprioception are getting ever more relevance as an integral part of healthcare. Exergaming embeds serious games within physical exercise especially to improve motivation towards tasks that can be boring and difficult to perform correctly. As the literature still lacks papers investigating the integration of training devices in SGs, we ad-hoc developed a hardware and software IoT exergaming system in order to address three main research questions about how to improve the user experience when using a typical balance/proprioception tool such as the BB.

According to user tests, performed by 40 healthy users, the proposed ski SG design was proven proper and effective in aiding the use of the BB. We showed that the score of the game can be an estimate of the user's balance capability progress as long as the guidelines and procedure implemented in the experiment are followed. Moreover, the overall experience using this system was positively assessed by users. A clear and training-goal-focused score function, together with simple but realistic 3D game features (e.g., landscape, character motion, and physics) in the context of a well-known, compelling sports activity, such as skiing, demonstrated to be key game mechanics enabling a positive experience with the overall system. The results of the tests show quantitative as well as subjective evidence that the presented exergame supports enjoyment and immersion while boosting the BB users' balance capacity. Carefully designed and tuned in-game score has been shown to correlate well with (self-assessed) users' equilibrium skills. A statistically significant score difference has been found between the first and the last test rounds, which highlights the training effectiveness of the developed system. We believe that these findings from the proposed RQs are important to inform the design of new effective exergames, which we propose to the SG R&D community.

Also according to the presented questionnaire results, the exergame design requires some enhancements in the video game environment, by increasing the quality of sounds and graphics. Porting of the system to different types of fitness boards and devices should be undertaken and verified, in order to generalize it, and make it useful in a variety of contexts. More items will be added to the questionnaire to better capture the user feedback. Moreover, future user tests should be performed considering the system for therapy/rehabilitation.

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