PsychNology Journal, 2015
Volume 13, Number 1, 57 – 74

Comparisons of Two Commercial and Two Low-cost Interfaces for Virtual Skiing

Niels Christian Nilsson[*1], Stefania Serafin[1] and Rolf Nordahl[1]

[1]Aalborg University
(Denmark)

ABSTRACT

In this paper we present two comparisons of two novel physical interface for interacting with a virtual environment in the form of a skiing game. The interfaces were compared through two separate within-subjects studies. In the first study we compared a wobble board augmented with a low-cost 3D accelerometer with the Wii Balance Board, and in the second study we compared a step machine augmented with the same accelerometer with the Wii Balance Board. Keyboard and mouse peripherals were included in both studies in order to see how the novel interfaces and the Wii Balance Board would measure up against these commonly used input devices. The interfaces were evaluated in terms of performance, perceived ease of use, and enjoyment. The results of the first study show that participants reported the wobble board to be the hardest to control, although their performance was better than using the Wii Balance Board. A positive correlation was found between reported enjoyment of the interface and easiness to control it. The results of the second study show that participants found the step machine to be the most enjoyable and the second easiest. In both studies the mouse and keyboard peripherals were superior in terms of performance and perceived ease of use.

Keywords: *Input devices, interfaces, interaction, virtual environment, skiing game, exergaming.*

1. Introduction

In the last decades, several alternative interfaces for computer games have appeared, both in the commercial and in the academic world. The use of such interfaces to interact with various forms of virtual environments, including games, has started receiving attention in relation sports and healthcare.

To mention a few, Alankus, Lazar, May, and Kelleher describe a system that enables patients who have suffered a stroke to perform control different games with gestures captured by means of a web camera or Wii remotes and thereby perform

Cite as:
Nilsson, N. C., Serafin, S. & Nordahl, R. (2015). Comparison of a Commercial and Two Low-cost Interfaces for Virtual Skiing. *PsychNology Journal, 13*(1), 57 – 74. Retrieved [month] [day], [year], from www.psychnology.org.

[*]Corresponding Author:
Niels Christian Nilsson
Aalborg University Copenhagen, A.C. Meyers Vænge 15, 2450 København SV, Denmark
E-mail: ncn@create.aau.dk

therapeutically beneficial upper body movements (Alankus, Lazar, May and Kelleher, 2010). Munih, Novak, Milavec, Ziherl, Olensek and Mihelj (2010) describe a multimodal system that similarly is intended to motivate stroke patients to exercise by combining challenges requiring mental effort with repeated, robot-aided physical actions in a game-like scenario. Deutsch, Latonio, Burdea and Boian (2001) describe an application developed for The "Rutgers Ankle" Rehabilitation Interface (Girone, Burdea and Bouzit, 1999) that allows users to control airplane movements with their feet and thereby train their ankles while playing.

Particularly, games have received attention because these may serve as a potential source of intrinsic motivation, that is, the form of motivation that incites individuals to perform an activity for no other reason than the act of performing the activity itself (Denis and Jouvelot, 2005). Applications capitalizing on this ability to provide individuals with an incentive to perform training or exercises that otherwise would have been perceived as trivial or cumbersome are sometimes referred to as exergaming (Bogost, 2005) or exertainment (Zabulis, Sarmis, Grammenos and Argyros, 2009).

Sinclair, Hingston and Masek (2007) outline a series of design consideration for exergaming systems. In particular, they discuss the role of the input device and describe that the amount of attention assigned to the input device itself may greatly influence the player's experience of the game. If the attention has to be placed on the gameplay, the input device needs to be intuitive to use and almost transparent. This may be explained by referring to Saariluoma (2005) who describes that our limited attentional capacity is restricted to one item at a time. However we possess mechanism enabling us to circumvent these limitations. One of these mechanisms is automatization, which relates to how a given action may become automatized after repeated execution of under similar conditions. Once a task is fully automated its demands on cognition diminishes, speed and efficiency increase, and performance becomes effortless and possibly even unconscious, thus enabling it to be performed alongside a more controlled main task. Notably, Febretti and Garzotto (2009) describe that a user's desire to continue playing a given game may be greatly influenced by the usability of the interface. Particularly, usability errors – which draw attention to the interface – may be detrimental to this desire.

Finally, Sinclair, Hingston and Masek (2007) highlight the importance of flow (Csikszentmihalyi, 1990) in relation to exergames since it may help ensure that the player continues playing and archives the desired health befits. Nakamura and Csikszentmihalyi (2002) describe that flow arises when an individual performs an activity of interest where the perceived challenges correspond to the perceived skills. The subjective state itself is characterized by intense and focused attention, merging of action and awareness, the loss of self-consciousness, a sense of control, distortion of temporal experience, and finally the experience of the activity as being intrinsically rewarding.

In this paper, we describe two alternative foot based interfaces intended for exergaming, namely, a wobble board and a step machine augmented with an accelerometer, which are used to interact with a game-like skiing simulation. We describe how the two interfaces were evaluated through comparisons with two commercially available input devices, the Wii Fit Balance Board, and a mouse and keyboard. Besides from demonstrating that the two interfaces constitute meaningful input devices for virtual skiing, the results provide relevant insights about how the use of such interfaces influences performance, ease of use and enjoyment.

The remainder of the paper is organized into eight sections. Initially the interfaces included in the comparisons will be described. The subsequent section introduces the game and describes how the real world interaction with the interfaces was mapped to movements in the virtual environment. The following two sections describe the two studies performed with the intention of evaluating the augmented wobble board and step machine. Finally we present a discussion of the findings of the two evaluations and conclude upon these. The last section of the paper is an appendix outlining relevant technical specifications.

2. The Interfaces

2.1 Augmented Wobble Board

A traditional wobble board is a relatively inexpensive device for strengthening one's ankles. The board consists of a circular disk on top of a centered semi-sphere (Figure 1). The board has three degrees of movement as it can be fully rotated about the vertical axis and partly rotated about the transverse and longitudinal axis. The user uses the board by standing on top of the disk while performing a series of exercises. These exercises include balancing on the board while keeping it as steady as possible, tilting the board steadily from side to side or back and forth, and performing circular clockwise or counterclockwise movements (Asp, Halldòrsdòttir, Hägg, Møller, Mickelsson, Boldt and Skaarup, 2007). Such boards may be used preemptively or as part of a rehabilitation process and has been proven to significantly reduce the risk of future ankle sprains and the residual symptoms of such sprains as well improving static and dynamic balance (Balogun, Adesinasi and Marzouk, 1992; McGuine and Keene, 2006; Wester, Jespersen, Nielsen and Neumann, 1996).

Figure 1. Side view of the wobble board (www.denintelligentekrop.dk) used for the interface.

The augmented wobble board used for the current evaluation has undergone several iterations and has been used as a controller for several multimodal virtual environments (Asp et al., 2007; Nilsson, Serafin and Nordahl, 2012a; Nilsson, Serafin and Nordahl, 2012b). The tilt angle of the wobble board is tracked by means of a Phidget 3-axis accelerometer retrofitted inside board (Figure 2). This type of accelerometer was used since the API provides out of the box USB support and no further processing is needed before the data can be read by Unity 3D.

Figure 2. Phidget 3-axis Accelerometer retrofitted inside the wobble board.

2.2 The Step Machine

The augmented step machine was created for the purpose of the second evaluation described in section 5. For this particular study, we choose a step machine by Gamercize (www.gamercize.net). Such machines enable users to perform movements similar to walking, with varying resistance, and thus strengthen the leg muscles and perform cardiovascular exercise (Figure 3). Although the machine already has a step sensor embedded in order to be used to control PC commands, we preferred to have continuous instead of discreet control. For this reason, a Phidget 3-axis accelerometer was used to determine the angle of one of the two foot platforms, which are moving asynchronously up and downwards.

Figure 3. The step machine used for the interface.

2.3 The Wii Balance Board

The Wii Balance Board was launched in 2007 as an accessory for the Nintendo Wii. Upon its release it was intended to be used as an input device when playing Wii Fit which is a game featuring yoga, strength, balance, and aerobic training. The yoga and strength training bears semblance with a traditional workout since the player gets the assistance from a virtual instructor when performing the exercises on the board. The balance and aerobic training is comprised of a series of mini-games designed to improve the player’s balance or as cardiovascular workouts.

Several studies have focused explicitly on the Wii Balance Board and its efficacy as a tool for alleviating balance disorders (Graves, Ridgers, Williams, Stratton, and Atkinson, 2011; Nitz, Kuys, Isles and Fu, 2010). In particular, Gil-Gomez, Lozano, Alcañiz, and Perez (2009) present a virtual rehabilitation system designed to be used in the patient's home. This system uses a conventional PC and the Wii Balance Board to enable users to perform exercises specifically designed for the rehabilitation of postural instability and balance disorders. Moreover, in a longitudinal study, the Wii Balance Board was used by an 86 years old patient five weeks after stroke. The patient reported greatly enjoying the treatment, although more detailed studies are necessary to verify its efficacy (Brown, Sugarman and Burstin, 2009). Moreover, the board has also been used as an interface for virtual travel (Krammes Filho, Sarmiento, Jorge, Collazos and Nedel, 2012; Wang and Lindeman 2012; Williams et al., 2011).

3. The Skiing Game

3.1 Gameplay at a Glance

The designed game was inspired by the now classic skiing game Mogul Maniac – a two-dimensional slalom course skiing game – and the associated input device, the Joyboard, which in many regards can be viewed as a technologically inferior predecessor to the Wii Balance Board (Bogost, 2007). One of the main reasons why Mogul Maniac lent itself well as a source of inspiration is that it involves a simple challenge which does not require any other interaction than navigation. While this navigational task may be relatively easy to perform, it is very difficult to master. Particularly, the designed game required the player to ski down a slope along a predetermined path as fast as possible while passing through as many gates as possible. When going down the virtual slope, the player is presented with two pieces of information at all times: the elapsed time and score. The player is awarded one point for each of the 31 gates that were cleared while going down the slope. The game was implemented using the multiplatform game development environment Unity 3D. A screenshot from the skiing game can be seen in Figure 4.

Figure 4. A screenshot of the skiing game used for both studies. The game is seen from a first person perspective, and in the top of the screen a blue head-up display presents information about the current time and the number of cleared gates. The green highlights presented in the gates are included in order to make these more easily visible to the player.

3.2 Mapping

The different input devices involve rather different physical movements on behalf of the player. Thus unique mappings between the four sets of player movements and their virtual counterparts were created. Figure 5 illustrates the four mappings used for each input device. Note that the highest possible speed and acceleration were identical for all mappings.

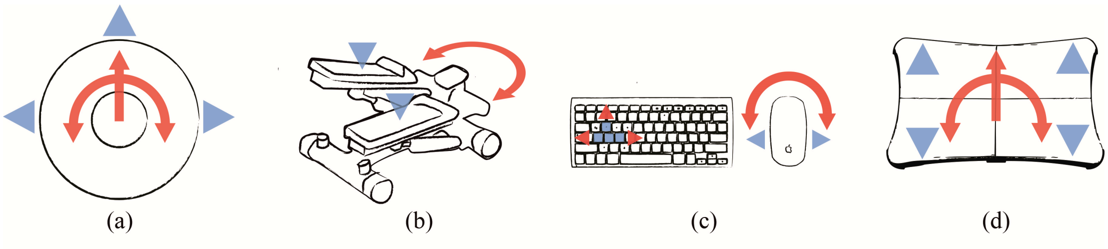

Figure 5. The four mapping strategies used for each of the four input devices. (a) Wobble board: Tilting the board to the left or the right results in a turn in either of the two directions and tilting the board forward entails forwards movement. (b) Step machine: When facing downhill speed is gained and downwards pressure with the left or right foot resulted in a turn in the opposite direction. (c) Keyboard and mouse: The keys w, a, s, and d controls the acceleration and deceleration and right and leftwards movement. The mouse is use to rotate to either the left or right. (d) Wii Balance Board: Leaning forwards or backwards results in acceleration and deceleration, respectively, and leaning to the left or right result in movement in the corresponding directions.

4. Study I

The first comparison involved the wobble board, the Wii Balance Board and the keyboard and mouse. The keyboard and mouse condition was included in order to provide information about how the alternative input devices would measure up against a conventional form of input for first person games.

4.1 Participants

A total of 10 volunteers partook in the evaluation, 8 males and 2 females, with a mean age of 23.9 (SD = 2.5). Two male participants reported having suffered leg injuries in the past but stated that they were able to participate.

4.2 Methods and Materials

The evaluation of the three physical interfaces was performed in a closed and spacious room in order to prevent any distractions, and to ensure unrestrained movement on behalf of the participants. With exception of the three input devices, identical setups were used for all trials, namely, a 27 inch iMac with a 3.1 GHz Intel core i5 processor and 4GB of memory running Mac OS X version 10.6.8 and Unity 3D version 3.4, displayed full screen at the resolution of 2560 x 1440. An iMac wireless keyboard and Mac USB mouse were used for the keyboard trails. The Phidget21 plugin version 2.18 was used for the wobble board data acquisition and OSCulator version 2.10.7.1 for Wii Balance Board data. A schematic representation of the setup used for the wobble board and Wii Balance Board can be seen in Figure 6.

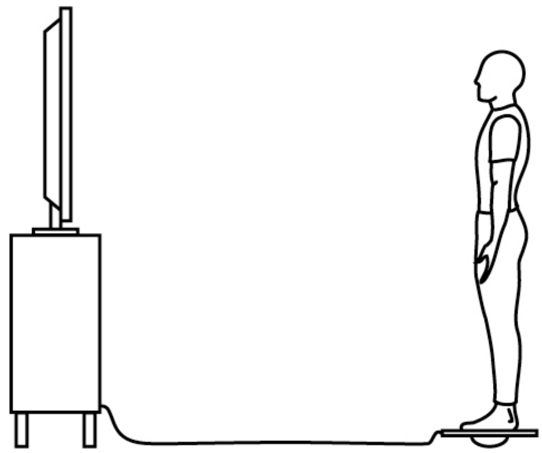

Figure 6. A schematic drawing of the setup. While the illustration shows the wobble board, the setup was virtually identical for the Wii Balance Board and the step master. The distance between the user and the screen were about 2m.

Initially the participants were presented with a scripted introduction to the game and informed of what was required of them in the following three trails. The path down the slope was the identical across all trials, which were performed in randomized order. Before each trial the participants were asked to familiarize themselves with each interface – the wobble board, Wii Balance Board and the keyboard and mouse – by going down the slope once.

After completing the three trials the participants were asked to compare the three interfaces by filling out a questionnaire. The questionnaire consisted of a series of items requiring the participants to rate the degree to which they agreed with particular statements on a scale from ‘1’ to ‘7’. Particularly, they were asked to rate each input device in terms of its ease of use and the level of enjoyment on scales ranging from poor (‘1’) to excellent (‘7’). Moreover, the participants were asked to provide qualitative feedback on any problems that they might have experienced in each of the tests and additional comments for further insight.

4.3 Results

The results pertaining to the performance and self-reported measures have been summarized in Figure 7. Repeated-measures analyses of variance (ANOVAs) were used to compare the means obtained from each of the four measures. All ANOVAs were performed using a significance level of α = .05. Significant differences were found in relation to completion time ($F(2, 29) = 24.6$, $p = .000007$), game score ($F(2, 29) = 19.6$, $p = .00003$), and perceived ease of use ($F(2, 29) = 4.4$, $p = .03$). No significant difference was found between the means obtained from the self-reported measure of enjoyment. Subsequently post-hoc analyses were performed by comparing the means with paired sample, one tailed t-tests using Bonferroni-corrected alphas (α = .017). The p-values obtained from these pairwise comparisons have been summarized in Table 1.

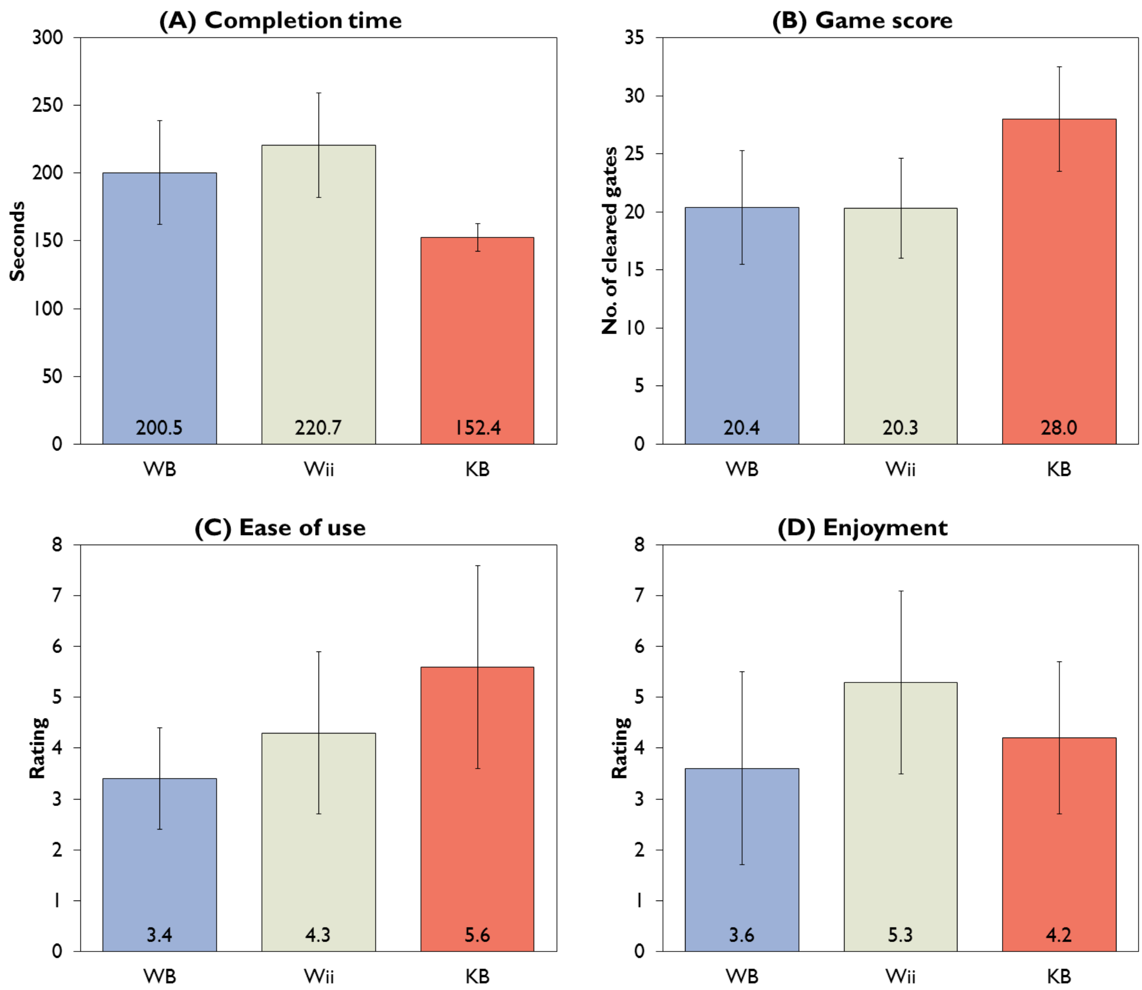

Figure 7. Means ± one standard deviation pertaining to the performance measures (A and B) and the self-reported measures (C and D) used in the first study. WB = wobble board, Wii = Wii Balance Board, and KB = Keyboard and mouse.

	WB - Wii	WB - KB	Wii - KB
Completion time	**0.0031**	**0.0013**	**0.0001**
Game score	0.4701	**0.0002**	**0.0003**
Ease of use	0.0606	**0.0112**	0.0846
Enjoyment	**0.0082**	0.2413	0.1263

Table 1. P-values obtained from paired sample, one tailed t-tests. WB = wobble board pertaining to the performance measures used in the first study. WB = wobble board, Wii = Wii Balance Board, and KB = Keyboard and mouse. Values indicating a significant difference are highlighted with bold ($\alpha = 0.017$).

The data obtained from the four measures were tested for correlations using Pearson's correlation. These comparisons yielded a significant correlation between completion time and game score ($r(30) = -.63$, $p = .0001$) indicating a strong negative relationship between the two variables. Positive relationships were found between perceived ease of use and game score ($r(30) = .55$, $p = .0008$) and between perceived ease of use and enjoyment ($r(30) =.51$, $p = .002$).

5. Study II

The second comparison involved the step machine, the Wii Balance Board, and keyboard and mouse. As before the mouse and keyboard was included in order to provide information about how the input devices would measure up against a conventional physical interface.

5.1 Participants

A total of 10 people partook in the evaluation, 7 males and 3 females, with a mean age of (mean = 23.1, SD = 2.4). All participants reported that they were in normal physical health.

5.2 Methods and Materials

The setup, procedure and employed measures were identical to the ones used during the first comparison (section 4.2).

5.3 Results

Figure 8 details the results obtained from the performance and self-reported measures used during the second study. As in case of the first study, repeated-measures ANOVAs (α = .05) were used to compare the means obtained from each of the four measures. Significant differences were found in relation to completion time ($F(2, 29) = 34.9$, $p = .0000006$), game score ($F(2, 29) = 12.7$, $p = .0004$), and perceived ease of use ($F(2, 29) = 9.6$, $p = .001$). The comparison of the means pertaining to the self-reported measure of enjoyment did not yield a significant difference. Again post-hoc analyses were performed with paired sample, one tailed t-tests using Bonferroni-corrected alpha values (α = .017). The p-values obtained from these pairwise comparisons have been summarized in Table 2.

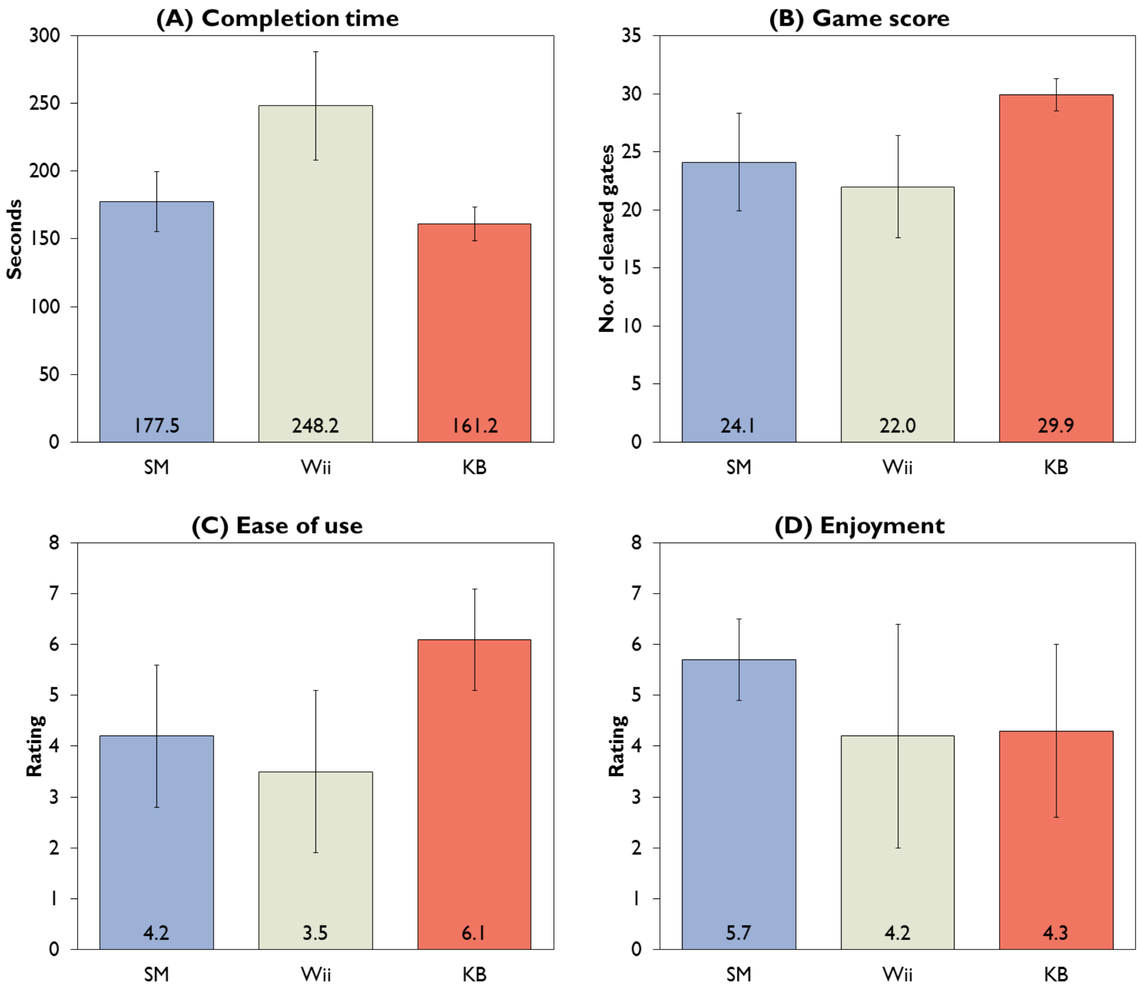

Figure 8. Means ± one standard deviation pertaining to the performance measures (A and B) and the self-reported measures (C and D) used in the second study. SM = step master, Wii = Wii Balance Board, KB = Keyboard and mouse.

Pearson's correlation was used to test the data for correlations. A significant positive correlation was found between perceived ease of use and game score ($r(30) = .69$, $p = .00001$) and significant negative correlations were found between perceived ease of use and completion time (r(30) = -.57, p = .0004) and between game score and competition time (r(30) =.43, p = . 008).

The measure of the participants overall experience of the game, yielded a mean of 5.5 ± 0.8, and the question related to their desire to continue playing produced an average score of 5.3 ± 0.4.

Finally it is worth noting that the results from trials involving the wobble board and Wii Balance Board were compared across study I and II by means of two tailed t-tests. These comparisons did not yield any significant differences.

	SM - Wii	SM - KB	Wii - KB
Completion time	**0,0001**	**0,0164**	**0,0001**
Game score	0,1602	**0,0007**	**0,0003**
Ease of use	0,1046	**0,0051**	**0,0028**
Enjoyment	0,0261	0,0359	0,4660

Table 2. P-values obtained from paired sample, one tailed t-tests. WB = wobble board pertaining to the performance measures used in the second study. SM = step master, Wii = Wii Balance Board, KB = Keyboard and mouse. Values indicating a significant difference are highlighted with bold (α = 0.017).

6. Discussion

The first comparison revealed some clear indications in regards to the participants' performance. The participants generally performed better when using the keyboard and mouse to control the game. They completed the game significantly faster and managed to pass through significantly more gates. Notably, the participants were significantly faster when controlling the game by means of the wobble board compared to the Wii Balance Board. Moreover, the difference in speed did not negatively appear to influence precision since no significant difference was found between the mean game score pertaining to the two interfaces.

The superiority of the mouse and keyboard controls was also reflected in means pertaining to the perceived ease of use of the three interfaces. However, a significant difference was only found between the means related to the mouse and keyboard and the wobble board, which in average were scored the highest and lowest, respectively. The fact that the wobble board was perceived as the most difficult interface does, however, not come as a surprise since the act of balancing on the board even without playing the game may pose a challenge to novices. In regards to the participants' experience of enjoyment, the Wii Balance Board appears to have elicited the most enjoyable experience while the wobble board was experienced as the least enjoyable. It seems plausible that the perceived difficulty of this interface may have negatively influenced the experience. Indeed a positive correlation was found between the perceived ease of use and enjoyment across the three interface types. It is interesting to note that there is a discrepancy between the objective measures of the participants' performance and their subjective experience of their own proficiency at using the interface. That is to say, the participants found the wobble board harder than the Wii Balance Board even though they in average achieved a better completion time with the wobble board and got a similar number of points with the two interfaces. Here it is worth drawing attention to the fact that there was no correlation between perceived ease of use and completion time, but a positive relationship did exist between perceived ease of use and game score. One plausible explanation is that the participants in regards to the completion time did not have any success criteria to compare their own performance against. Conversely the participants did know that there were a total of 31 gates along the ski slope, and they therefore had an ideal results with which they could compare their game score.

Finally it is worth noting that, while the analysis of the data revealed a positive correlation between perceived ease of use and enjoyment, no significant correlations were found between any of the two performance measures and the experience of enjoyment.

The second study also revealed clear indications in regards to the participants' performance. Again, the keyboard and mouse proved to be superior to both of the other input devices in terms of both completion time and game score. Unlike the wobble board, the step machine yielded both faster completion times and higher game scores than the Wii Balance Board. However, a significant difference was not found in regards to latter. This insignificant difference notwithstanding, it would seem that the relatively high speeds obtainable with the step master do not come at the expense of precision. As in the first study, the superiority of the mouse and keyboard controls was also reflected by the ratings of the perceived ease of use.

Despite being statistically insignificant, it is worth noting the difference between the means pertaining to the perceived ease of use of the step machine and the Wii Balance Board. Since Bonferroni-correction comes with a risk of false negatives, this difference may be worth considering, albeit with caution. Particularly, it does seem possible that the step machine may have been easier to use since it presumably is the input device where the required movement resembles real skiing the most.

An interesting discrepancy between the two studies exists in regards to the ratings of enjoyment. In the first study the Wii Balance Board was rated more enjoyable than the keyboard, but the two means are close to identical in the second study. Moreover it is interesting to note that step machine was perceived as the most enjoyable. However, none of the means related to the enjoyment of the interfaces were significantly different in the second study.

Contrary to the first study, no correlation between enjoyment and perceived ease of use was found. In the first study a discrepancy was found between the objective measures of the participants' performance and their subjective experience of their own proficiency at using the interface. The same was not the case in the second study since participants consistently rated interfaces associated with higher performance as easier to use. A significant correlation was found between perceived ease and both performance measures.

Looking at the results across the two studies, it is worth noting that the wobble board led to faster completion times than the step machine whereas the participants cleared more gates when using the step machine compared to the wobble board. Moreover, the step machine scored higher than the wobble board with respect to the both perceived ease of use and enjoyment. A possible explanation is that the movement performed while using the step machine bears greater semblance with the movement performed when skiing, thus increasing the naturalism of the interaction (Bowman, McMahan and Ragan, 2012). Bowman, McMahan and Ragan (2012) define the naturalism (also referred to as interaction fidelity) of a user interface (UI) *"[...] as the objective degree with which the actions (characterized by movements, forces, or body parts in use) used for a task in the UI correspond to the actions used for that task in the real world"* (p. 79).

Moreover, the fact that the participants performed the best when using the keyboard and mouse is in line with the suggestion that increased performance does not naturally follow from an increase in interaction fidelity (Bowman, McMahan and Ragan, 2012). Indeed evidence suggests that very high levels of interaction fidelity may improve performance compared to lower levels of interaction fidelity. However, the same need not be the case in relation to moderate levels of interaction fidelity, which in some cases even may be detrimental to performance (McMahan, 2011).

7. Conclusion

In this paper, we have described the design and evaluation of two alternative foot based interfaces for interacting with a virtual environment in the form of a skiing exergame – a wobble board and a step machine augmented with an accelerometer.

The results of the first evaluation indicated that the interface that was most enjoyed, the Wii Balance Board, was the slowest and the number of cleared gates was as bad as it was when using the wobble board. However the reported ease of use pertaining to the Wii Balance Board was relatively high. Moreover, it is worth mentioning that, the qualitative feedback obtained during the evaluation showed that participants were wary about correcting their foot placement when using the wobble board as they would lose control.

The results of the second study show that participants found the step machine to be the most enjoyable and the second easiest. In both studies the mouse and keyboard peripherals were superior in terms of performance and perceived ease of use.

With that being said, it is important to stress that the limited sample sizes of both studies prevent us from drawing unequivocal conclusions based on the results. Thus, it would be relevant for future studies, involving larger sample sizes, to investigate how the wobble board and step machine compare with one another and other traditional input devices (e.g., joysticks and gamepads) as interfaces for virtual skiing and other forms of interaction within virtual environments.

8. Appendix: Technical Specifications

To acquire data to Unity 3D a Phidget21 plugin installation was required. For the Wii Balance Board the data was sent to Unity3D through a port by OSC routing with a program called OSCulator. The keyboard and mouse was implemented using the standard first person controller in Unity 3D.

The mapping for each interface was chosen to be the same speed, acceleration, sliding and backwards speed to equally assess each interface. This was adjusted through a built in motor script in Unity 3D. For the wobble board the mapping was adjusted in a Phidget.bundle to the built motor script in Unity 3D. The X axis rotation controlled forward and backward momentum while the Z axis rotation controlled Y axis rotation and strafe. The same mapping technique was applied using the motor script to the Wii Balance Board by using Wiimotetuio. The difference was that the center of mass was calculated in the case of the Wii Balance Board and applied on direction and rotation. The mapping for the keyboard and mouse was implemented by adjusting the built in first person controller in such a way that forward, backward, acceleration and left and right strafe momentum was controlled by ‘w’, ‘s’, ‘a’ and ‘d’ keys and the mouse was limited to controlling the rotation along the Y axis. In all cases the rotation of the perspective on the X axis was therefore fixed as was in Mogul Maniac. A pilot test with 5 participants for each interface was performed to adjust each mapping in regards to speed, acceleration and to evaluate the combination of rotation and strafe for both the wobble board and the Wii Balance Board. Some adjustments were made to the mapping. Scripts were written, to update the timer and score and UnityGamePlayMetrics scripts were integrated into the project to track the player’s position over time and save the data in XML format.

9. References

Alankus, G., Lazar, A., May, M., & Kelleher, C. (2010, April). Towards customizable games for stroke rehabilitation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2113-2122).

Asp, S. E., Halldòrsdòttir, K. Ò., Hägg, C., Møller, M. L., Mickelsson, B. P., Boldt, L., & Skaarup, D. (2007). WobbleActive. In *Proceedings of the 1st International Symposium on Ludic Engagement Design for All 2007*. Aalborg University Esbjerg.

Balogun, J., Adesinasi, C., & Marzouk, D. (1992). The effects of a wobble board exercise training program on static balance performance and strength of lower extremity muscles. *Physiotherapy Canada*, *44*, 23-23.

Bogost, I. (2005). The rhetoric of exergaming. *Proceedings of the Digital Arts and Cultures (DAC)*.

Bogost, I. (2007). Persuasive games: The expressive power of videogames. Mit Press.

Bowman, D. A., McMahan, R. P., & Ragan, E. D. (2012). Questioning naturalism in 3d user interfaces. *Communications of the ACM*, *55* (9), 78-88.

Brown, R., Sugarman, H., & Burstin, A. (2009). Use of the nintendo wii fit for the treatment of balance problems in an elderly patient with stroke: A case report. International *Journal of Rehabilitation Research*, 32, S109-S110.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience* (Vol. 54). Harper and Row.

Denis, G., & Jouvelot, P. (2005, June). Motivation-driven educational game design: applying best practices to music education. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology* (pp. 462-465).

Deutsch, J. E., Latonio, J., Burdea, G. C., & Boian, R. (2001). Post-stroke rehabilitation with the Rutgers Ankle System: a case study. *Presence: Teleoperators and Virtual Environments*, *10* (4), 416-430.

Febretti, A., & Garzotto, F. (2009, April). Usability, playability, and long-term engagement in computer games. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems* (pp. 4063-4068).

Gil-Gomez, J. A., Lozano, J. A., Alcañiz, M., & Perez, S. A. (2009, June). Nintendo Wii Balance Board for balance disorders. In *Virtual Rehabilitation International Conference, 2009* (pp. 213-213).

Girone, M., Burdea, G., & Bouzit, M. (1999). The Rutgers Ankle orthopedic rehabilitation interface. *Proc. ASME Dyn. Syst. Control Div*, 67, 305-312.

Graves, L. E., Ridgers, N. D., Williams, K., Stratton, G., & Atkinson, G. T. (2010). The physiological cost and enjoyment of Wii Fit in adolescents, young adults, and older adults. *Journal of physical activity & health*, *7* (3), 393-401.

Krammes Filho, H. F., Sarmiento, W. J., Jorge, V. A., Collazos, C., & Nedel, L. (2012). Walk in Place Using a Balance Board Matrix. In *Proceedings of Workshop on Works In Progress, SIBGRAPI 2012*.

McGuine, T. A., & Keene, J. S. (2006). The effect of a balance training program on the risk of ankle sprains in high school athletes. *The American journal of sports medicine*, 34 (7), 1103-1111.

McMahan, R. P. (2011). Exploring the Effects of Higher-Fidelity Display and Interaction for Virtual Reality Games (Doctoral dissertation, Virginia Polytechnic Institute and State University).

Munih, M., Novak, D., Milavec, M., Ziherl, J., Olensek, A., & Mihelj, M. (2011, June). River multimodal scenario for rehabilitation robotics. In *Rehabilitation Robotics (ICORR), 2011 IEEE International Conference on* (pp. 1-6).

Nakamura, J., & Csikszentmihalyi, M. (2002). The concept of flow. *Handbook of positive psychology*, 89-105.

Nilsson, N. C., Serafin, S., & Nordahl, R. (2012a). Gameplay as a source of intrinsic motivation for individuals in need of ankle training or rehabilitation. Presence: *Teleoperators and Virtual Environments*, 21 (1), 69-84.

Nilsson, N. C., Serafin, S., & Nordahl, R. (2012b, March). The Fwobble: continuous audio-haptic feedback for balance control. Poster session presented at *3D User Interfaces (3DUI), 2012 IEEE Symposium on* (pp. 153-154).

Nitz, J. C., Kuys, S., Isles, R., & Fu, S. (2010). Is the Wii Fit™ a new-generation tool for improving balance, health and well-being? A pilot study. *Climacteric*, *13* (5), 487-491.

Saariluoma, P. (2005). Explanatory frameworks for interaction design. In *Future interaction design* (pp. 67-83). Springer London.

Sinclair, J., Hingston, P., & Masek, M. (2007, December). Considerations for the design of exergames. In *Proceedings of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia* (pp. 289-295).

Wang, J., & Lindeman, R. W. (2012, March). Comparing isometric and elastic surfboard interfaces for leaning-based travel in 3D virtual environments. In *2012 IEEE Symposium on 3D User Interfaces* (3DUI) (pp. 31-38).

Wester, J. U., Jespersen, S. M., Nielsen, K. D., & Neumann, L. (1996). Wobble board training after partial sprains of the lateral ligaments of the ankle: a prospective randomized study. *Journal of Orthopaedic & Sports Physical Therapy*, *23* (5), 332-336.

Williams, B., Bailey, S., Narasimham, G., Li, M., & Bodenheimer, B. (2011). Evaluation of walking in place on a wii balance board to explore a virtual environment. *ACM Transactions on Applied Perception* (TAP), 8 (3), 19.

Zabulis, X., Sarmis, T., Grammenos, D., & Argyros, A. A. (2009, May). A Multicamera Vision System Supporting the Development of Wide-Area Exertainment Applications. In *MVA* (pp. 269-272).