A Spinal Column Exergame for Occupational Health Purposes

Sergio Valdivia[1], Robin Blanco[1], Alvaro Uribe[3(✉)], Lina Penuela[1], David Rojas[2], and Bill Kapralos[3]

[1] Universidad Militar Nueva Granada, Bogota, Colombia
sergiodragoon@gmail.com, {u3900208,lina.penuela}@unimilitar.edu.co
[2] The Wilson Centre, Toronto, ON, Canada
davidrojasgualdron@gmail.com
[3] University of Ontario Institute of Technology, Oshawa, ON, Canada
alvaro.j.uribe@ieee.org, bill.kapralos@uoit.ca

Abstract. Sedentary, bad posture, and repetitive movements are the leading cause of several health problems, including spinal column pain, which, can lead to work absenteeism, deterioration of the quality of life, and surgery in extreme cases. Physical activity and exercise can reduce the risk of spinal column problems, and pain. However, sustaining healthy habits, such as exercising, requires motivation and engagement. Exergames are becoming more relevant thanks in part to the use of wearable technologies that provide compelling, engaging, and motivating experiences that can help improve health care. In this work, we present the development of a spinal column occupational health exergame and a study on engagement with two motion tracking technologies, a Microsoft Kinect V2 sensor, and an inertial measurement device. Results indicate, that the inertial measurement unit performs better than Microsoft's Kinect V2, but the game was perceived as more engaging using Microsoft's Kinect V2.

Keywords: Exergame · Posture tracking · 3DUI

1 Introduction

Approximately 83% of the world's population lives with some form of a musculoskeletal disorder (MSD) due to sedentary, bad posture, and repetitive movements as a result of workplace activities, amongst others [1]. Additionally, the ubiquitous use of computing, and mobile devices both in the workplace and in our personal lives, is leading to greater health risks. MSDs may result in work absenteeism, reiterative visits to medical facilities, physiotherapy, and surgery in chronic cases [2]. Currently, physical activity remains the best option to prevent work-related MSDs [3], through typically short and slow-paced upper, lower and back flexion and extension movements, often performed without supervision [1]. Improper execution of physical activity may lead to health problems that could

J. Dias et al. (Eds.): GALA 2017, LNCS 10653, pp. 83–92, 2017.
https://doi.org/10.1007/978-3-319-71940-5_8

worsen a MSD. This is particularly the case when the physical activity is performed without supervision, where printed and multimedia guides provide the instructions for performing the exercises, leaving the patient without feedback as to how the exercise is being performed [4].

The monitoring and assessment of physical activity plays an important role in assessing progression and providing adjustments to exercise routines. Traditionally, progress assessment has relied on observation, self-reports, and questionnaires that may not provide an accurate overview of the physical activity progression [5]. In sports, physical activity measurements employ high-end motion capture systems based on infrared cameras and gait laboratories, amongst others [6]. In contrast, wearable technologies and motion tracking systems supported by consumer electronic devices, have arisen as consumer-level solutions that can impact a wider range of the population [7].

Despite the inclusion of newer technologies that can provide physical activity feedback, there still exists an underlying challenge associated with a lack of motivation and engagement [8]. As an example, consider the Nintendo Wii remote control (commonly referred as the Wiimote), a video game controller that provided motion-based interactions by employing an accelerometer and a gyroscope [9]. The Wiimote has been applied in health care settings including, the rehabilitation of patients who suffered a stroke [10], and Parkinson patients [11]. Following the success of the Nintendo Wii, Microsoft launched the first version of the Microsoft Kinect, an image-based sensor that allows body motion tracking through stereo cameras to provide natural interactions within gaming [12]. Similarly to the Wiimote, the Microsoft Kinect has also been employed in health care settings for physiotherapy [13]. Currently, open electronics, 3D printing, and inertial measurement units (IMUs) are providing low-cost, consumer-level wearable motion capture alternatives [14].

The coupling of video games and exercise, whereby playing a video game becomes a form of physical activity, is known as exergames [15]. Exergames may increase engagement [16], reduce pain perception [17], and enhance retention and understanding of the physical activity [18]. Although the application of exergames has been primarily oriented to physiotherapy and rehabilitation, there are additional applications in fitness [19], obesity prevention [20], and treatment and prevention of eye [21], hands [22], and lower/upper limbs occupational health problems [23].

This paper describes the design and development of a spinal column exergame as a tool to promote exercise amongst office workers who spend more than seven hours each day seated in front of a computer. Engagement is provided through carefully chosen game mechanics coupled with the physical activity, while motion interactions are captured with two sensors, a Microsoft Kinect V2 and an IMU to analyze the performance with the exergame and without it.

The remainder of this paper is organized as follows: Sect. 2 describes the game analysis and design from a learning-game mechanics perspective. A description of the experimental design is provided in Sect. 3. Experimental results of the preliminary study conducted to examine the engagement capabilities of the exergame, and a comparison of the movements performed between the exergame and a game-less version using different motion tracking devices are provided in Sect. 4. Concluding remarks and plans for future work are provided in Sect. 5.

2 Development

The development of the exergame requires the analysis of the spinal column to determine the ranges of motion and exercising characteristics that define the design process. The spinal column is comprised of five sections: the cervical, thoracic, lumbar, coccidea, and sacrum [24]. Most common back problems are related to the lumbar area due to damage caused by bad posture, overuse, or exceeding forces [25]. Physical activity focused on flexion and extension frontal rotations can alleviate pain, realign the vertebrate, and strengthen the abdominal muscles [26].

2.1 Game Mechanics and Learning Mechanics

The exergame design process is similar to that of "traditional" (entertainment) video games and follows the same structure where game elements are chosen to achieve the intended goal [27]. However, exergames require additional considerations and care to provide suitable interactions that do not affect the game progress and feedback, and are within the user's mobility capacities. While exergames focus on physical activity, they also present learning opportunities to create awareness while playing. To design our exergame, we followed the exergame design of Sinclair, Hingstone, and Masek where attractiveness, effectiveness, input devices, flow, and event tracking are considered as key parameters [28]. Additionally, to further extend our exergame functionality, we employed the analysis of learning and game mechanics conducted by Arnab et al. from where we chose motivation, ownership, competition, and clear instructions with feedback (see Table 1) [29].

Table 1. Identified game and learning mechanics and implementation description.

Game mechanics	Learning mechanics	Implementation and use
Exercise demonstration	Instructions Demonstration Shadowing	The game instructs the proper execution of a movement
Indication of execution	Feedback Imitation	Proper exercise execution rewards the player
Scores	Motivation Competition	Score is awarded as a result of well performed movements
Goals	Motivation Competition Planning	Game goals provide intrinsic motivation

2.2 Game Design

The game design included the definition of the rules based on the physical activity comprised of paced flexion and extension back movements performed during a minute, game mechanics associated to the effects of movement that allows painting a room accordingly to the amplitude of the movement, and the goal of the exergame, consisting in performing five repetitions and fully paint the room. The exergame was implemented using the Unity3D game engine as it allows cross-platform compilation and compatibility with the Arduino open-source platform (used to acquire motion data from the IMU), and the Microsoft Kinect V2 video-based sensor.

To achieve the motion tracking with the Microsoft Kinect V2, we configured its software development kit, and obtained the position data for the 21 body joints tracked by the sensor. We chose the spine-base and the spine-mid joints to record movements associated with the lumbar and thoracic spinal column areas during flexion and extension. The sensor takes samples on 30 Hz with a latency of 60 ms that can be affected by the hardware characteristics of the computer running the sensor.

Motion tracking with the IMU was achieved by employing an Arduino UNO board, and IMU MPU-9250 nine degrees of freedom sensor (i.e., three accelerometer axis, three gyroscope axis, and three magnetometer axis measurements), with a resolution of 16 bits and configurable measuring range, that supports data sampling at 400 kbps. The IMU was strapped to an elastic band worn by the user. To avoid the use of a tether and possible interference of a wired connection, we designed the Arduino motion capture system to work wirelessly with Bluetooth and with a portable battery.

The exergame scenario is comprised of a white room that will be painted through the user's frontal and lateral spinal column flexion and extension movements obtained from the sensors. To achieve the goal of painting the room and account for the differences amongst users, the range of movement can be customized in the calibration stage, allowing to define the motion thresholds. The objective for the customization is to maintain the users within the game flow area with proper tracking to avoid possible overwhelming difficulties [30]. The game indicates which movements are to be performed through visual cues employing an avatar mimicking the user. To further increase user immersion, the painting color changes according to the executed movements. Figure 1 presents the graphical user interface (GUI), and the virtual avatar mimicking the user that provides visual feedback that may help to correct and improve a movement. It is worth noting that motion tracking with the IMU provides spinal column movements only, thus the arms of the avatar do not move as can be seen from Fig. 1.

3 Experimental Design

We designed and conducted a preliminary experiment to measure the engagement capabilities of the exergame, and to gauge the participant's perceptions

Fig. 1. GUI and virtual avatar motion tracking with the Microsoft Kinect V2 sensor and the IMU.

after playing it, while acquiring motion data employing a Microsoft Kinect V2 sensor and IMU sensor, along with a game-less version. Brockmyer et al. [31] defined engagement loosely as "a generic indicator of game involvement". The experiment was comprised of the following stages: (i) an explanation phase where the facilitators presented the exergame and the motion capture technologies to the participants, (ii) a calibration stage where the facilitator asked the participants to complete the flexion and extension five times as they would do without any gaming component, (iii) an exercising stage with a duration of one minute where the participants positioned in front of a television and the Microsoft Kinect V2 sensor, started interacting with the GUI through the flexion and extension movements, and received feedback from the game, (iv) participants were presented a IMU-based version of the exergame that required them to perform the exercises with a duration of a minute, and finally, (v) the assessment of the exergame where participants completed the Game Engagement Questionnaire (GEQ) [31].

The GEQ contains 19 questions and provides a psychometrically strong measure of levels of engagement specifically elicited while playing video games [31]. Each question can be responded to with one of three options: (i) No, (ii) Maybe, and (iii) Yes, where each option is assigned a numerical value of -1, 0, and 1 respectively. The questions of the GEQ are grouped into the four categories of (i) immersion, (ii) presence, (iii) flow, and (iv) absorption, where -1 represents the lowest engagement perception, while 1 the maximum one, and any value in-between indicates that further work is required to increase the engagement.

3.1 Participants

We invited ten participants to use the spinal column exergame, of whom five used the version of the game that employed the Microsoft Kinect V2 sensor, and five used the version of the game that employed the IMU. Additionally, each participant performed the physical activity with a game-less version of the exergame, while maintaining the same motion capture device.

All participants confirmed working more than seven hours in front of a computer and expressed not exercising their backs while acknowledging the importance to do so.

4 Results

4.1 Microsoft Kinect V2 Data Capture

Participants who played the exergame with the Microsoft Kinect V2 sensor reported a minimum average flexion of 15.4° and a maximum average flexion of 75.6. Figure 2 presents a sample from one participant flexion and extension execution with and without the exergame. It can be observed from the captured data that without the exergame the participant executed the movements as best as possible, but over-exceeding the flexion tracking range. However, when participants focused on performing the exercise as fast as possible without the exergame, the Microsoft Kinect V2 measurements indicate data loss due to the inability of the sensor to keep track of rapid movements in detail. This was corrected with the exergame, as the movements were presented in a slower-paced form that allowed acquiring more accurate information. Results indicate that the use of the exergame allows the participants to perform the movements more consistently and with similar amplitude or angle range, as can be seen in Fig. 2.

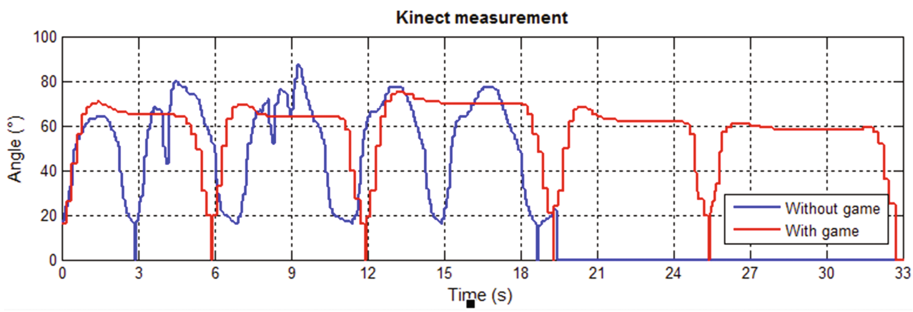

Fig. 2. Microsoft Kinect V2 spinal column motion tracking comparison with and without the exergame. Blue - motion tracking without the game. Red - motion tracking with the game. (Color figure online)

4.2 IMU Data Capture

The participants who used the exergame with the IMU presented a 5.7° minimum flexion and a maximum of 71.2° on average. Motion-tracked data with the complementary filter programmed in Unity to process the Arduino board signals resulted in a minimum noise level under one degree which was disregarded, proving adequate for motion tracking purposes. Similar to the measurements obtained with the Microsoft Kinect V2 sensor, Fig. 3 presents the motion tracked data of

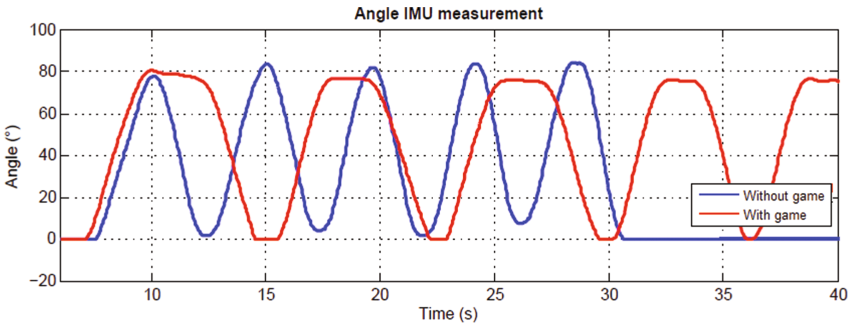

Fig. 3. IMU spinal column motion tracking comparison with and without the exergame. Blue - motion tracking without the game. Red - motion tracking with the game. (Color figure online)

a single user performing the flexion and extension movement with and without the exergame.

Interestingly, the data captured with the IMU allows observing a paced execution with flexion ranges that allow keeping the user within the visibility of the sensor. Additionally, although in this case the participant performed the movements faster without the exergame, the data is more accurate and adequate to assess the motion range, which, in comparison with the Microsoft Kinect V2 sensor provides more reliability.

4.3 GEQ Analysis

The results of the GEQ provided engagement insights while playing the game with the Microsoft Kinect V2 sensor and the IMU. As previously described, the GEQ includes four categories for measuring engagement including immersion, presence, flow, and absorption [31]. Although several definitions can be found for these four terms, here we present the definitions described by Brockmyer et al. [31]: (i) immersion is the experience of becoming engaged in a virtual experience while being aware of one's surroundings, (ii) presence is being in a normal state of consciousness while being inside a mediated virtual environment, (iii) flow describes the feelings of enjoyment as a result of the interaction balance between skill and challenge, and finally (iv) absorption is the total engagement within the virtual scenario that causes an altered state of consciousness.

The GEQ results (as presented in Table 2), indicate that those who played the game where the tracking was accomplished using the Microsoft Kinect V2 sensor perceived it as being more immersive than with the game that employed the IMU, even though these obtained the same GEQ score. We believe the increase in immersion was the result of the Microsoft Kinect V2 sensor motion tracking capabilities, as it can detect body movements from 26 joints resulting in the avatar mirroring the participant's movements more naturally, while the IMU was configured to only capture the back flexion and extension and all body parts remain static. Presence was higher for the exergame that employed the IMU, and we believe this occurred as a result of the lag of movements present while using the Microsoft Kinect V2 sensor. The flow was overall poorly rated with both tracking technologies indicating that the relation between skill and challenge needs to be improved to take better advantage of the motion-based interaction with the game mechanics. Finally, absorption presented the lowest of the four scores, indicating the need of improvements in taking further advantage of the game elements to alter the state of consciousness of the players.

Table 2. GEQ gathered data for all four categories (*IMU Captured data)

Participant	1	2	3	4	5	Mean
Immersion	1	1	1	1	1	1
	1*	0*	−1*	1*	0*	0.2*
Presence	0.25	0	0.5	0	0.5	0.25
	0.75*	0.5*	0.5*	0.5*	1*	0.65*
Flow	0.23	−0.34	0	−0.12	0.12	−0.02
	−0.12*	0.34*	0.45*	0*	0.56*	0.24*
Absorption	−0.4	−0.2	−0.6	−1	−0.4	−0.52
	−0.6*	0.2*	0.6*	0.2*	0.6*	0.2*

5 Conclusions and Discussion

Here we have presented the design and development of an exergame aimed at low-back care. We employed the Microsoft Kinect V2 sensor and a IMU with an Arduino Uno board to obtain measurable spinal column flexion and extension data from a series of five repetitions. To gauge the engagement perception of the exergame, we compared participant performance with the Microsoft Kinect V2 sensor and an IMU. The GEQ provided relevant information that can help us improve the exergame. From the motion captured data, it was interesting to observe the differences from both sensors, and how the participants approached the goal of exercising with and without the gaming component. With respect to the sensors, the Microsoft Kinect V2 sensor provided a more immersive experience and its compatibility with numerous commercial exergames adds expectation to the users. However, the IMU excelled at better capturing the ranges of movement, proving to be a better device for motion tracking. Additionally, the IMU and the Arduino provided an interesting complement that could be integrated to commercial exergames to provide further data that can assist users in better understanding their progress during the physical activity.

Future work will focus on improvements regarding immersion, presence, flow, and absorption to maximize the effects of the game mechanics. In addition, we will conduct research on improving the acquisition of the data towards developing a framework that allows multiple physiological measurements, increase the number of participants, and analyses over time to understand the possible effects of time of using the exergame.

Acknowledgements. The authors would like to thank Universidad Militar Nueva Granada for funding Project ING-2377.

References

1. Luttmann, A., Jager, M., Griefahn, B., Caffier, G., Liebers, F., Organization, W.H., et al.: Preventing musculoskeletal disorders in the workplace (2003)
2. World Health Organization: WHO — Occupational and work-related diseases. WHO (2012)
3. Brownson, R.C., Hoehner, C.M., Day, K., Forsyth, A., Sallis, J.F.: Measuring the built environment for physical activity: state of the science. Am. J. Prev. Med. **36**(4), S99–S123 (2009)
4. Cromie, J.E., Robertson, V.J., Best, M.O.: Occupational health and safety in physiotherapy: Guidelines for practice. Aust. J. Physiotherapy **47**, 43–51 (2001)
5. Craig, C.L., Marshall, A.L., Sjöström, M., Bauman, A.E., Booth, M.L., Ainsworth, B.E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J.F., et al.: International physical activity questionnaire: 12-country reliability and validity. Med. Sci. Sports Exerc. **35**(8), 1381–1395 (2003)
6. Bassett, D.R.: Validity of four motion sensors in measuring moderate intensity physical activity. Med. Sci. Sports Exerc. **32**(9), S471–S480 (2000)
7. Rosenberger, M.E., Buman, M.P., Haskell, W.L., McConnell, M.V., Carstensen, L.L.: Twenty-four hours of sleep, sedentary behavior, and physical activity with nine wearable devices. Med. Sci. Sports Exerc. **48**(3), 457–465 (2016)
8. Reichert, F.F., Barros, A.J., Domingues, M.R., Hallal, P.C.: The role of perceived personal barriers to engagement in leisure-time physical activity. Am. J. Public Health **97**(3), 515–519 (2007)
9. Wingrave, C.A., Williamson, B., Varcholik, P.D., Rose, J., Miller, A., Charbonneau, E., Bott, J., LaViola Jr., J.J.: The wiimote and beyond: Spatially convenient devices for 3d user interfaces. IEEE Comput. Graphics Appl. **30**(2), 71–85 (2010)
10. Brosnan, S.: The potential of wii-rehabilitation for persons recovering from acute stroke. Phys. Disabil. **32**(1), 1–3 (2009)
11. Herz, N.B., Mehta, S.H., Sethi, K.D., Jackson, P., Hall, P., Morgan, J.C.: Nintendo wii rehabilitation (Wii-hab) provides benefits in parkinson's disease. Parkinsonism Relat. Disord. **19**(11), 1039–1042 (2013)
12. Zhang, H.: Head-mounted display-based intuitive virtual reality training system for the mining industry. Int. J. Min. Sci. Technol. **27**(4), 717–722 (2017). Special Issue on Advances in Mine Safety Science and Engineering
13. Luna-Oliva, L., Ortiz-Gutiérrez, R.M., Cano-de la Cuerda, R., Piédrola, R.M., Alguacil-Diego, I.M., Sánchez-Camarero, C., C, M.C.: Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: a preliminary study. NeuroRehabilitation **33**(4), 513–521 (2013)
14. Case, M.A., Burwick, H.A., Volpp, K.G., Patel, M.S.: Accuracy of smartphone applications and wearable devices for tracking physical activity data. JAMA **313**(6), 625–626 (2015)
15. Pirovano, M., Surer, E., Mainetti, R., Lanzi, P.L., Borghese, N.A.: Exergaming and rehabilitation: A methodology for the design of effective and safe therapeutic exergames. Entertainment Comput. **14**, 55–65 (2016)

16. Campbell, R., Evans, M., Tucker, M., Quilty, B., Dieppe, P., Donovan, J.: Why don't patients do their exercises? Understanding non-compliance with physiotherapy in patients with osteoarthritis of the knee. J. Epidemiol. Community Health **55**(2), 132–138 (2001)
17. Malloy, K.M., Milling, L.S.: The effectiveness of virtual reality distraction for pain reduction: a systematic review. Clin. Psychol. Rev. **30**(8), 1011–1018 (2010)
18. Macvean, A., Robertson, J.: Understanding exergame users' physical activity, motivation and behavior over time. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1251–1260. ACM (2013)
19. Brauner, P., Calero Valdez, A., Schroeder, U., Ziefle, M.: Increase physical fitness and create health awareness through exergames and gamification. In: Holzinger, A., Ziefle, M., Hitz, M., Debevc, M. (eds.) SouthCHI 2013. LNCS, vol. 7946, pp. 349–362. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-39062-3_22
20. Vander Schee, C.J., Boyles, D.: exergaming, corporate interests and the crisis discourse of childhood obesity. Sport Educ. Soc. **15**(2), 169–185 (2010)
21. Navia, M., Uribe-Quevedo, A.: Development of an eye tracking occupational health game. In: 1st International Workshop on Assistive Technologies (2015)
22. Ortiz, S., Uribe-Quevedo, A., Kapralos, B.: Hand VR exergame for occupational health care. In: MMVR, pp. 281–284 (2016)
23. Ramos-Montilla, E., Uribe-Quevedo, A.: Development of an open electronics user inerface for lower member occupational health care exergaming. In: Stephanidis, C. (ed.) HCI 2015. CCIS, vol. 529, pp. 478–483. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-21383-5_80
24. Gianino, J.M., Paice, J.A., York, M.M.: Spinal cord anatomy. Intrathecal Drug Therapy for Spasticity and Pain, pp. 3–14. Springer, New York (1996)
25. Adams, M.A.M.A.: The biomechanics of back pain. Churchill Livingstone/Elsevier (2013)
26. Adams, M.A., Bogduk, N., Burton, K., Dolan, P.: The Biomechanics of Back Pain. Elsevier Health Sciences (2012)
27. Fullerton, T.: Game Design Workshop: A Playcentric Approach to Creating Innovative Games. CRC Press (2014)
28. Sinclair, J., Hingston, P., Masek, M.: 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. ACM (2007)
29. Arnab, S., Lim, T., Carvalho, M.B., Bellotti, F., Freitas, S., Louchart, S., Suttie, N., Berta, R., De Gloria, A.: Mapping learning and game mechanics for serious games analysis. Br. J. Educ. Technol. **46**(2), 391–411 (2015)
30. Cowley, B., Charles, D., Black, M., Hickey, R.: Toward an understanding of flow in video games. Comput. Entertainment (CIE) **6**(2) (2008). 20
31. Brockmyer, J.H., Fox, C.M., Curtiss, K.A., McBroom, E., Burkhart, K.M., Pidruzny, J.N.: The development of the game engagement questionnaire: A measure of engagement in video game-playing. J. Exp. Soc. Psychol. **45**(4), 624–634 (2009)