Using the Smartphone Accelerometer to Monitor Fall Risk while Playing a Game: The Design and Usability Evaluation of Dance! Don't Fall

Paula Alexandra Silva[1,2], Francisco Nunes[1,3], Ana Vasconcelos[1], Maureen Kerwin[1], Ricardo Moutinho[1], and Pedro Teixeira[1]

[1] Fraunhofer Portugal – AICOS, Rua Alfredo Allen, 455, 4200-135 Porto, Portugal
{ana.vasconcelos,ricardo.moutinho,pedro.teixeira}@fraunhofer.pt, mkkerwin@gmail.com
[2] University of Hawaii, POST Building, 309C, 1680 East-West Rd, Honolulu, HI 96822
paulaalex@hawaii.edu, palexa@gmail.com
[3] Vienna University of Technology, Argentinierstrasse 8, Vienna, Austria
francisco.nunes@igw.tuwien.ac.at

Abstract. Falls are dangerous, and unfortunately common for older adults. Dance! Don't Fall is a game that assesses the quality of the user's locomotion based on data from the accelerometer of a smartphone. By providing a form of exercise, the game may actually reduce fall risk as well as monitoring it. In this paper, we document the development of the prototype and a usability study with ten seniors that suggested the game is well suited to its primary users.

Keywords: Fall risk assessment, older adults, mobile applications, physical activity, dance games.

1 Introduction

Falls are the most common cause of injury and injury-related death among older adults (65+), and one in three older adults suffers a fall every year [1]. To assess fall risk, doctors conduct clinical tests and administer questionnaires [2] [3]. However, these are rarely used before a fall occurs. Furthermore, the infrequency of the tests – once every couple of months – renders them ineffective for detecting sudden changes.

One of the major factors contributing to fall risk is decreased strength and flexibility caused by a lack of physical activity [1], so counteracting the trend of increasingly sedentary lifestyles is a key way to prevent the occurrence of falls.

Our systematic observation and interaction with older adults in a number of senior centers in Portugal has evidenced that older adults particularly enjoy dancing. However, they often are not able to dance because of a lack of specific opportunities, and the difficulty of fitting classes or events into their schedules [4]. Researchers at Fraunhofer Portugal (FhP) - AICOS developed Dance! Don't Fall[1] (DDF), a dance

[1] Dance! Don't Fall is available at http://dancedontfall.projects.fraunhofer.pt

D.D. Schmorrow and C.M. Fidopiastis (Eds.): AC/HCII 2013, LNAI 8027, pp. 754–763, 2013.

game that monitors users' fall risk, while potentially reducing it by promoting systematic exercise. DDF builds upon previous technology developed for conducting and evaluating the gait test using a smartphone as a sensor that the user wears against his or her lower back [5]. This technology was developed with biomedical experts, and includes the clinical gait test and questionnaires in the smartphone. In the same way, DDF provides a means to administer clinical tests at home while it enables and motivates users to exercise regularly, thereby reducing their risk of falling in the first place. The goal of this paper is to present the design and development of DDF as well as the major results of its usability evaluation. Although relevant, assessing the accuracy of the fall algorithm and the long-term efficacy of the game for health purposes are out of the scope of this paper.

2 Related Work

A number of topics contextualize this research, from serious games to games for health, and exergames. Serious games were first approached by Clark Abt, who argued that games should be used as educational tools because of their ability to communicate facts in an efficient way that motivates people to play and, consequently, learn [6]. Later, in the early 2000s, David Rejeski and Ben Sawyer founded the Serious Game Initiative with the goal of spreading the use of games as a means of facing the challenges of the modern world [7]. Since then, serious games have been widely adopted within a variety of areas including military, government, education, business, politics, religion, art, and healthcare [8].

Associated with the Serious Games Initiative, games for health seek to improve healthcare through games that positively impact both mental and physical health [9], educating for healthy habits [11], training and diagnosing cognitive skills [12], complying with rehabilitation programs [14], and improving motor skills [15].

Exergames are a specific kind of game for health that combine exercise and gaming [16]. By adding an element of fun to exercise, exergames can improve seniors' physical and mental health [17]. Exergames have gained popularity with Nintendo's Wii console, but the first commercially successful exergame was Dance Dance Revolution (DDR), which began as an arcade game [18]. DDR players stand on a pad with colored arrows and step on them according to the visual cues on the screen. DDR and similar games are known to provide exercise, helping players become more physically fit and lose weight [19]. However, games like DDR are not adapted to older adults' needs. They include fast-paced music, frequent jumping, and an overload of information on the screen [20]. Moreover, dance pads not only limit the versatility of the stepping pattern, but are also dangerous, as their smooth surfaces can cause them to slip out from underneath players' feet and lead to falls [16]. Nonetheless, DDR inspired researchers to explore dance games for seniors. Smith et al. developed a modified version of DDR and conducted tests with people aged 70+ [21]. Their results showed seniors were able to use the system, but their error rate grew as the step speed and rate increased.

Dancetown is a PC-based exergame specifically designed for seniors. It is similar to DDR as it also uses a dance pad and requires players to follow on-screen cues. Dancetown also includes a rail that can be used with the pad to prevent falls. The

graphics accommodate weakening eyesight, and the game uses music from past generations that may appeal to older users [22]. Studies concluded that the exercise provided by Dancetown is an effective and fun alternative to traditional aerobic exercise; anecdotal findings also indicated that seniors enjoyed playing the game [23].

Finally, DanceAlong [4] is a dance game targeted at seniors that allows players to do "Movioke" – that is, to dance along with scenes from popular movies. This system was tested at a community senior center and players responded enthusiastically, mainly due to the social component of the game.

3 Process

The DDF project followed an iterative and user-centered process with all phases occurring in less than two months. It was the result of an effort of three different teams working concurrently: one designed the user interface, another developed the engine to recognize the dance moves, and another implemented the user interface and developed the communication system that enables multiplayer dances.

The design team, comprised of user interface designers and an element with previous experience in dancing, began by conducting video and live observations of dances in order to identify the characteristics that a dance game system for older adults should have. These revealed that dancing is an activity naturally done together, choreographies are typically simple and repetitive, many dances are derived from traditional dances, and dance steps are in general smooth and small. Furthermore, clapping and producing sounds with the hands seem to be an important part of the dance, not only helping to keep the rhythm, but also stimulating enthusiasm. These were therefore the tenets for the design of DDF, which was initially prototyped on paper and then iteratively refined in terms of functionality, information architecture, and graphic design. In parallel, the design team also chose a song and began working on the dance choreography, which was also iteratively refined, based on feedback from the dance recognition engine team, to ensure the system would be able to detect the dance steps with a sufficient degree of accuracy.

The dance recognition team's work extended the previous work that enabled a smartphone to run a gait test [5]; this algorithm was extended to perceive backward and sideways steps in addition to forward steps. The team developed the rules for step detection by analyzing and testing accelerometer signals from smartphones to discover patterns. The team used Audacity[2] to analyze the music and define the times that steps should occur. They initially implemented the engine in Python using the SciPy open source library of scientific tools, and later ported it to the Android mobile operating system.

[2] Audacity is an open-source software for recording, editing and analysing sound. For more information, refer to: `www.audacity.sourceforge.net`.

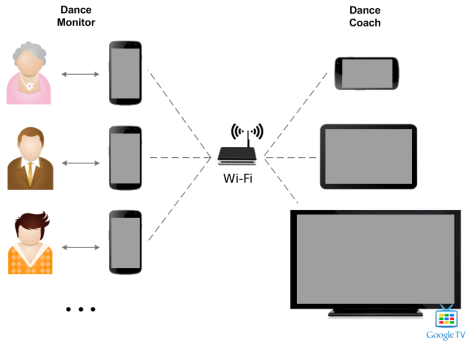

Fig. 1. Multiple devices can be used to play DDF using a Wi-Fi connection

The third team began by implementing the game's user interfaces and basic functionalities. Once the dance engine reached a functional level, it was incorporated into the main Android application and synchronized with the dance choreography for further testing. At this time, the development team focused its resources on the development of the multiplayer component, which was iteratively improved until it was stable and could provide the desired functionality without additional configurations.

4 The DDF System

DDF is a Game for Health that monitors fall risk. To play DDF, the user wears a smartphone on the lower back that tracks his or her dance steps. As users perform choreographed moves along with audio or video dance instructions, the system's algorithms analyze the smartphone's accelerometer data to give feedback on both dance performance and risk of falling. The game gives feedback on four aspects of the dance performance: accuracy, timing, stability, and grooviness. For every dance, the score for each of these factors can be LOW, OK, or HIGH. The fall risk assessment is based on the quality of the user's locomotion and is complemented by a brief questionnaire, presented when a problem appears to exist.

There are three ways to play DDF: Learn, Perform, and Compete. In Learn, a virtual dance coach teaches the individual dance steps and then outlines the choreography. After having learned the choreography, the user may choose Perform to dance alone, or Compete to challenge other friends to a group dance contest. DDF currently features one song and dance, which is based on a simple line dance choreography[3]. As discussed below, more dances should be included in the future.

4.1 Physical Architecture

DDF only requires one smartphone to play the game, but when other Android devices are nearby they can be connected to enhance the user experience and promote social play (Fig. 2). When the game is launched and the device is connected to a Wi-Fi network, the system automatically searches the network for other compatible devices

[3] The team chose a line dance - commonly associated with country-western music and featuring a group of people facing the same direction and performing the same sequence of steps - because the application was intended for presentation at the Mobile Apps Showdown of the Consumer Electronics Show and thus targeted at an American market; furthermore, line dances easily accommodate the characteristics deemed necessary for a dance for seniors.

(Android smartphones or tablets and Google TVs). The user may opt to run additional devices in either dance monitor or dance coach mode, depending on the number and type of devices present.

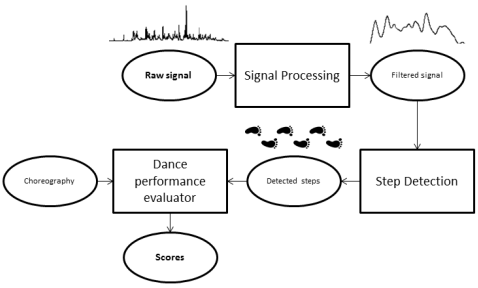

Fig. 2. The processed accelerometer signal is compared to the choreography to score a dance.

Fig. 3. Participants almost exclusively relied on the silhouette to follow the dance.

4.2 Game Modes: Dance Monitor and Dance Coach

The dance monitor is the default mode that includes the game's core mechanics. It requires one smartphone running DDF and is able to detect the steps and play instructions. In addition, the application detects other players in the network and establishes a connection, allowing several players to play simultaneously.

The dance coach mode is an extension that enables players to watch a synchronized dance instructor on another screen. This mode can run on another smartphone, but works best on a tablet or Google TV. Devices running this mode synchronize with the players' smartphones and present the players' ranking at the end of a dance.

4.3 Dance Recognition Engine

The dance monitor mode is powered by the dance recognition engine, which outputs the user's evaluation based on the acceleration of the pelvis, a music track, and a technical definition of the corresponding choreography (comprised of the parts of the dance that are walking-like steps forward, backward, and to the sides). The dance recognition engine contains three modules: a signal processing module, a step detection module, and a dance performance evaluator module. The output of each module respectively serves as the input for the next module (Fig. 3).

The signal-processing module calibrates the raw accelerometer signals, enabling the alignment of the phone's axis with directions relative to the body. Afterwards, a low pass filter with cut-off based on the music frequency is applied, both eliminating the signal's noise and emphasizing the components corresponding to steps. The output of this module is then input to the step detection module.

The step detection module considers different components of the acceleration depending on the direction of movement being performed and outputs a list of perceived steps, each characterized by a timestamp and a direction.

The dance performance evaluator receives a list of steps and compares it to the choreography, which is composed of pairs consisting of a timestamp (the time from the start of the track when the step is supposed to take place) and a direction (the intended movement for the step). Based on the results of this comparison, the module outputs four parameters indicating the performance of the dance:

- Accuracy – the number of correct steps divided by the number of expected steps, a correct step being a step with the same direction as the closest step within a 500 millisecond window in the choreography;
- Timing – the delay between the step's timestamp and the music's time;
- Grooviness – the intuitive sense of dancing in time, evaluated by a combination of pelvic sway and timing; and
- Stability – a measure of how much and how quickly the user performs lateral pelvic displacement.

5 Usability Evaluation of Dance! Don't Fall

The authors conducted a usability study of DDF to identify obstacles to using the system, evaluate the ease of learning and performing the dance, discover users' feelings about the experience, and determine key areas of future research. Ten participants (8 female, 2 male) from senior centers around the city of Porto, Portugal with ages ranging from 60-89 (average 74.2; median 74) took part in the study.

The study took place in the Assisted Living Laboratory at FhP - AICOS. The DDF application ran on both a Google TV and two Android smartphones that the participant and moderator used. The mobile application had been translated into Portuguese, the language used to conduct the tests.

Three team members facilitated the tests. One served as the moderator, giving the introduction and directions, participating in the dance competitions, and generally leading participants through the tests. The other facilitators observed and recorded the participants' behavior and comments; one observer also administered a debriefing interview at the end of the test. One camera recorded the tests from an angle behind the dancers, capturing the display on the TV. Another was attached to the TV and recorded the front view of the dancers, providing a record of the participants' facial expressions and body language.

The test sessions lasted about 45-60 minutes and consisted of an introduction explaining the test and procedures; six tasks, instructed to the participant one at a time; a debriefing interview; and a questionnaire about the participant's health. The tasks required participants to utilize the primary functions of the system, namely: i) input the necessary personal data; ii) accept a dance invitation; iii) comprehend the dance evaluation results; iv) start a dance alone; and v) invite another player to dance. In a normal test situation, each participant performed the dance three times.

6 Findings and Recommendations

Overall, the participants' reaction to the game was positive and they performed well, but the tests did reveal several ways to improve DDF. This section describes the main findings of the usability study.

DDF Is Relevant to the Target Audience. Participants confirmed the two key assumptions behind the game: falls are a frequent issue, and dance is a form of exercise older adults are fond of. Seven had had a fall and feared falling again; the others knew someone who had fallen. All participants stated they liked dancing very much. Eight indicated that they had danced often when younger, while the remaining two said they would like to learn now even though they had not danced much in the past. When inquired about the game itself, nine participants indicated they liked the game very much and would play it at home. The remaining participant did not like the dance style. To address this issue, a future version of the system should offer more variety, namely in terms of styles and levels of difficulty. Besides keeping users interested in the game, offering more difficult dances may also encourage improvement over time and make the game appeal to users with a wider range of fitness levels.

The User Interface Should Be Improved. The participants' ability to learn and perform the dance varied. Several participants performed the dance well from the beginning, some improved markedly with each attempt, while others still could not follow the steps after several attempts. To some extent the variation was caused by differences in physical ability – for instance, three participants turned around so slowly that they fell behind in the dance. But it also seemed to be a matter of the participants' ability to understand DDF's user interface. Nine participants reported they focused solely on the silhouetted demonstrating the dance, ignoring the icons and counter that indicate the current step and the number of times to do it, as well as advising the subsequent step (Fig. 4). This probably indicates an information overload users had when trying to simultaneously interpret the movements of the figure, reproduce them, and attempt to anticipate what to do next. It was not always easy to interpret and mimic the movements of the figure. One participant confused backward and forward steps, not knowing if she was watching the silhouette from the front or the back. Seven participants made errors with the left and right side steps, not sure whether they should mirror the figure or step to their own left or right. Six participants had difficulties performing a step that requires the player to clap and tap their foot at the same time – five only clapped, while one clapped and tapped on opposite beats. Presumably the errors were not due to the difficulty of actually performing the step, but because the participants did not notice the detail of the tapping foot. In addition, to a more clear visual representation of the steps, the inclusion of verbal instructions should be assessed as a way to improve the efficacy in conveying information about the dance steps. This issue, as well as a few others identified in the evaluation (e.g. unclear button labels or problems inputting data), should be addressed in a future version of the game.

DDF Should Emphasize Positive Feedback and Accommodate Beginners. The observers noted that the moderator strayed from the script to encourage and reassure participants: i) after a given participant received low scores (when the moderator typically commented that the participant had done very well considering he or she had just begun learning the dance), and ii) after the participant completed the fall risk questionnaire and received a risk warning (when the moderator assured the participant it was nothing to worry about). Encouraging comments should probably be incorporated in the user interface itself. In total, six participants received low scores and were invited to take the clinical questionnaire. This does not mean that participants had a particularly poor performance, but it shows that the system does not account for the time required to learn the dance. One way to address this is adding the ability to play the dance as a trial that does not receive a score.

7 Discussion

Despite the potential for improvement in the areas discussed above, DDF has several key advantages to other dance games, particularly for older adults. First of all, DDF does not require the purchase of a video game console or physical game media. Anyone who owns a smartphone meeting the minimum requirements can download and play the game at anytime, anywhere. It can be argued that gaming consoles are beginning to make their way into seniors' homes, but our experience with this audience makes us believe that the majority will see them as youth-oriented technology. Smartphones, on the other hand, are becoming more popular and have already conquered the pockets of 22% of U.S. seniors (65+) [24]. For them, DDF significantly lower in not only the effort but also the commitment required to try a new physical activity. Since the smartphone is a multi-purpose device, it has better chances of being welcomed by older adults that believe they are too old to play games. Likewise, DDF accounts for the fact that Google TVs are still fairly uncommon by enabling Android tablets and smartphones to act as the dance coach component in the absence of a Google TV. Furthermore, many of these devices can also duplicate the dance coach display onto a regular television set through HDMI. By supporting connection with large screened devices, DDF transforms itself into a more traditional gaming system and encourages players to dance as a group around the display. While DDF's dances cannot involve movements that are coordinated as pairs – since the system cannot distinguish multiple actors with different sets of movements – this form of group dancing is well-suited to older adults, since not having a partner is one factor that often prevents them from participating in dance activities [4]. Moreover, a study of a projection-based dance system for older adults revealed that participants enjoyed the feeling of dancing with others even though they did not have a designated partner [4].

A key advantage of DDF is the hands-free dance interaction made possible by leveraging the smartphone as a wearable sensor, which provides a more enjoyable and usable experience than games that require the use of an external control device. The most appealing aspect of the new generation of gaming consoles is the use of movement to control the game. However, both Nintendo Wii and PlayStation Move still

use a remote that players hold while playing, limiting the performance of certain gestures. In a study of a digital television exercise application, the participants enjoyed the exercise activities but were distracted by issues related to manipulation of the control device [25]. Likewise, currently available dance games often use game pads that, as stated above, are limiting and possibly dangerous. Microsoft's Kinect and the PlayStation Eye enable users to play without a physical controller. In this vein, DDF players wear the smartphone in a belt, giving them more freedom of movement.

8 Conclusions and Future Work

The usability study produced favorable results, indicating that DDF's objectives align with the goals of the intended primary audience. The evaluation also revealed ways to make the game more effective; but participants successfully completed tasks, enjoyed themselves, and wanted to play again regardless. Overall, the system proved a successful way to utilize the smartphone as a sensor for a dance game as well as assess fall risk through a gait test and questionnaire.

An important subject missing from this evaluation is the question of the game's health aims. How accurately does the system assess the user's dance performance, and how directly does this translate into fall risk? Moreover, what is the impact over time? Do users' results tend to improve as they play more, and does this truly decrease their risk of falling? Such questions are outside the scope of this evaluation but should be addressed in the future, through a more detailed, controlled, long-term study, planned with the collaboration of medical professionals.

References

1. Centers for Disease Control and Prevention. Falls among older adults: an overview, http://www.cdc.gov/HomeandRecreationalSafety/Falls/adultfalls.html
2. Protec-fall.com. Clinical tests evaluating gait and balance, http://www.protec-fall.com/screening-technics/67/clinical-tests-evaluating-gait-and-balance.html
3. Saskatoon Health Region. Fall-risk multi-factor questionnaire, http://www.saskatoonhealthregion.ca/pdf/06_MultiFactor_Falls_Questionnaire.pdf
4. Keyani, P., Hsieh, G., Mutlu, B., Easterday, M., Forlizzi, J.: DanceAlong: supporting positive social exchange and exercise for the elderly through dance. In: CHI 2005, Portland OR, pp. 1541–1544. ACM Press (2005)
5. Guimarães, V., Teixeira, P.M., Monteiro, M.P., Elias, D.: Phone based fall risk prediction. In: Nikita, K.S., Lin, J.C., Fotiadis, D.I., Arredondo Waldmeyer, M.-T. (eds.) MobiHealth 2011. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 83, pp. 135–142. Springer, Heidelberg (2012)
6. Abt, C.C.: Serious Games. Viking Press, New York (1970)
7. Serious Game Initiative, http://tinyurl.com/adh8ekp

8. Michael, D., Chen, S.: Serious Games: Games That Educate, Train, and Inform. Thomson Course Technology, Boston (2006)
9. Games for Health, http://www.gamesforhealth.org/
10. Hoffman, H.G., Patterson, D.R., Carrougher, G.J.: Use of virtual reality for ad-junctive treatment of adult burn pain during physical therapy: a controlled study. Clinical Journal of Pain 16(3), 244–250 (2000)
11. Baranowski, T., Baranowski, J., Cullen, K., Marsh, T., Islam, N., Zakeri, I., Honess-Morreale, L., Demoor, C.: Squire's Quest! Dietary outcome evaluation of a multi-media game. American Journal of Preventive Medicine 24(1), 52–61 (2003)
12. Jimison, H., Pavel, M.: Embedded assessment algorithms within home-based cognitive computer game exercises for elders. In: Proc. of the 28th Annual International Conference of the IEEE, EMBS 2006, pp. 6101–6104. IEEE Xplore, NY (August/September 2006)
13. Rosenberg, D., Depp, C.A., Vahia, I.V., Reichstadt, J., Palmer, B.W., Kerr, J., Norman, G., Jeste, D.V.: Exergames for subsyndromal depression in older adults: a pilot study of novel intervention. Am. J. Geriatr. Psychiatry 18(3), 221–226 (2010)
14. Lange, B., Chien-Yen, C., Suma, E., Newman, B., Rizzo, A.S., Bolas, M.: Development and evaluation of low cost game-based balance rehabilitation tool using the Microsoft Kinect sensor. In: EMBC 2011, pp. 1831–1834. IEEE Xplore, Boston (August/September 2011)
15. Jung, Y., Koay, J.L., Ng, S.J., Wong, L.C., Kwan, M.L.: Games for a better life: effects of playing Wii games on the well-being of seniors in a long-term care facility. In: IE 2009, Sydney, Australia. ACM Press (December 2009)
16. Bogost, I.: The rhetoric of exergaming (2005), http://bogo.st/cm
17. Brox, E., Luque, L.F., Eversten, G.J., Hernandez, J.E.G.: Exergames for elderly: Social exergames to persuade seniors to increase physical activity. In: PervasiveHealth 2011, Dublin Ireland, pp. 546–549 (May 2011)
18. Arntzen, A.: Game based learning to enhance cognitive and physical capabilities of elderly people: concepts and requirements. World Academy of Science, Engineering and Technology 60, 63–67 (2011)
19. DeMaria, R.: Reset: Changing the Way We Look at Video Games. Berrett-Koehler Publishers, Inc., San Francisco (2007)
20. Lange, B.S., Flynn, S.M., Chang, C.Y., Liang, W., Chieng, C.L., Si, Y., Nanavati, C., Rizzo, A.A.: Development of an interactive stepping game to reduce falls in the elderly. In: ICDVRAT 2010, Valparaíso Chile, pp. 223–228. ICDVRAT (August/September 2010)
21. Smith, S.T., Sherrington, C., Studenski, S., Schoene, D., Lord, S.R.: A novel Dance Dance Revolution (DDR) system for in-home training of stepping ability: basic parameters of system use by older adults. Br. J. Sports Med. 45(5), 441–445 (2011)
22. Canada.com. Senior citizens joining dance revolution, http://tinyurl.com/chh9cvv
23. Thomas, J., Porcari, J., Foster, C., Anders, M.: Dance the calories away: a critical look at Dancetown, an exer-game geared for older adults. ACE Fitness Matters, 9 (November/December 2009)
24. The Nielsen Company. Survey: new U.S. smartphone growth by age and income, http://tinyurl.com/872nlwv
25. Carmichael, A., Rice, M., MacMillan, F., Kirk, A.: Investigating a DTV-based physical activity application to facilitate wellbeing in older adults. In: BCS 2010, Dundee UK, pp. 278–288. ACM Press (September 2010)