Developing an exergame for unsupervised home-based balance training in older adults
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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2016

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

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Download date: 23-12-2018
Summary

More than one third of community living individuals aged 65 years and older falls at least once per year, regularly resulting in serious injuries such as major head trauma and fractures. Fall incidents are among the leading causes of injury and disability in seniors, and account for over 80% of the injury-related admissions of older adults to the hospital. In the Netherlands alone an estimated 15,000 older adults fracture their hip each year as a result from a fall. The cost of falls in the Netherlands are estimated at €780 million per year. To contribute to a solution for the high fall incidence among older adults, a problem analysis was performed (Chapter 1). The main cause of falls can be found in age-related deterioration of postural control, generally known as impoverished balance. It was concluded that although the fall risk of older adults can be lowered by training postural control through exercise-based programs, only few seniors participate in these activities. Barriers include the effort and cost of traveling, fear of falling, costs of training programs, and lack of motivation for training. A relatively new method for training postural control is through exergaming. Exergames (exercise videogames) are videogames that enable the player to perform training exercises in a fun and motivating virtual training environment. Over the last decade this concept has gained popularity in gyms and among young adults, but as of yet most exergames are not suitable for older adults. However, the potential that exergames hold for training balance in older adults is substantial. The aim of the current dissertation is therefore to develop and test a home-based exergame system specifically for older adults, thereby reducing fall risk.

Chapter 2 describes a review study which examines the state of art of exergames and sensor technology for balance training and quantification. Thirteen papers were included, of which ten papers reported improvements in at least one balance measure after a period of training. The number of controlled studies however was small (five) and studies were difficult to compare due to the large variety in sensors and outcome measures used. We conclude that the potential of exergames for training postural control is large, and suggest to utilize the recent advances in sensor technology, increasingly affordable computing power, and data analysis algorithms to enable quantification of balance during exergaming, thereby enabling continuous monitoring of postural control over time.

To decide on the content of the exergame that was to be developed in the current project, the requirements for the exergame system were defined (Chapter 3). First, the requirements of all stakeholders were examined in a workshop session. The results showed that the game should 1) train and measure postural control, 2) be user-friendly and suitable for unsupervised home-based use, 3) be suitable for selling as a consumer product and 4) rely on state of the art technologies. Second, the user requirements were studied by consulting a focus group of nine older adults through individually administered semi-structured interviews. After transcribing the interviews verbatim, transcripts were coded and analyzed qualitatively. It was found that elderly want an exergame that is not only fun, but has a proven health benefit, holds social elements and can be played in a multiplayer mode, is easy to operate, has options for regulating difficulty, holds realistic and imaginative components and costs at maximum €250,-. Third, the game concept of ice skating in a traditional Dutch landscape was defined in a workshop.
with the other stakeholders, and a concept version of the game was developed using the input from the focus group. In the game the user controls an ice skater on a frozen Dutch canal in a traditional winter setting. The exergame is controlled completely through bodily movements, which are captured using Kinect (Microsoft, Redmond, USA), a state of art videogame sensor that tracks the 3D position of individual body segments. The user controls the ice skater (the avatar) by making lateral whole-body sway movements, where increasing sway frequency and sway amplitude results in an increase of speed of the avatar. The concept version was then tested with twelve older adults. Based on these tests eleven recommendations were made which were used for further developing the exergame.

To examine the suitability of Kinect for measuring whole-body movement data and using these data to quantify postural control, we compared Kinect with a high-end marker-based Vicon V8 3D camera system (Vicon, Oxford, UK) (Chapter 4). Twenty healthy adults played the exergame under different conditions with varying amplitudes and speed of sway movement, while 3D positions of ten body segments were recorded using Kinect and Vicon. Movement patterns were identified in the recordings of both systems using principal component analysis, and the variance explained by these patterns in all body segments was computed. It was found that Kinect allows for accurate identification of movement patterns, yet the variance explained by these patterns in the extremities was off by as much as 30%. The trunk segments were measured more accurately, showing differences in the order of 5%. Using the movement patterns identified in the whole-body movement data recorded by both devices, balance outcome measures based on spatio-temporal sway characteristics were computed. Comparison of the results showed that differences between both systems with respect to balance outcome measures range 0.3-64.3%. Differences were largest in outcome measures relying on high spatial accuracy and in game conditions where body segments moved fastest. It was concluded that Kinect is suitable for capturing whole-body movement data while performing complex balance tasks in an exergame environment, yet the limitations found should be taken into account when using the data for balance quantification purposes.

In Chapter 5, the use of self-organizing feature maps (SOM) for quantification of postural control during exergaming was evaluated. Twenty young and twenty older adults played the exergame under five conditions while their movements were captured using Kinect. These data were then used (off-line) to train a SOM, identify movement patterns on the SOM, and compute variability in these patterns. The results showed that the variability in movement patterns on the SOM was significantly larger in older adults in the more challenging exergame conditions. Still, a trained K-nearest neighbors classifier was unable to discern young and older adults with high accuracy. Given the results of chapter 4, it is unlikely that the rather low discriminative power (65.8%) of the SOM is caused by the sensor used (Kinect). A more plausible explanation was found in the broad age range used in the study; young adults were up to 60 years old, whereas older adults were 65 years or older. We concluded that training a SOM with whole-body movement data captured with Kinect allows for quantification of postural control, and that further research is needed to implement these type of pattern recognition algorithms in exergames such that postural control can be measured during exergaming.
A final prototype of the exergame system was developed (Chapter 6) in which we took heed of the findings of chapter 3 and chapter 4. The game concept of controlling a virtual ice skater using weight shifts in lateral directions remained unchanged, but the game itself was completely redesigned to meet the requirements set in chapter 3. One of the most important changes was a more precise control mechanism of the avatar, such that it matches the users’ movements more closely. Other improvements included additional game features, improved graphics and more game content. The goal in the prototype exergame is to skate as fast as possible on frozen canals without hitting obstacles such as bridges and ice holes, which can be dodged by bending and leaning sideways respectively. The game can be played in two modes and holds three difficulty levels per mode. The prototype exergame runs on a mini-PC, which receives its input from Kinect, and is displayed on the television of the older adult.

The prototype was evaluated in a pilot study where ten older adults played the game at home and without supervision for a period of six weeks (Chapter 7). The older adults were instructed to play the game at least three time per week for 30 minutes, and sway characteristics during quiet standing were measured before, after two, four and six weeks of training. All subjects adhered to the program and it was found that balance significantly improved after four weeks. Significant differences in rate of improvement were observed between participants, underlining the importance of individualized training programs.

Chapter 8 discusses the findings of the dissertation and provides directions for future research. Next steps in the development of the current exergame include more game content, a multiplayer mode and defining a viable business model. Future exergame research should focus on integrating the algorithms used for quantification of postural control with the exergame. This opens the door to creating exergames that measure balance during gameplay and adjust the difficulty to the individual player, thereby personalizing the training program. Once these challenges are met, exergames are ready to shift paradigms and provide fun, social, effective and affordable training opportunities for older adults, thereby eventually reducing the number of falls.