A Smart Chair Physiotherapy Exergame for Fall Prevention

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***Abstract*—Older adults form a large and increasing proportion of the world's population, with falls representing one of the major causes of their mortality and morbidity. When considering the aging population, falls and fall-related injuries pose a major challenge, affecting continued ability to perform activities of daily living (ADLs), independence, and quality of life. With the emergence of smart furniture technologies, opportunities arise within the health and rehabilitation sector. Amalgamating technology with game orientated exercise (exergames) facilitates the delivery of entertaining, complimentary tools in the provision of preventative and rehabilitative intervention. In this study, a prototype physiotherapeutic exergame based on a smart chair was developed in collaboration with physiotherapists and game developers. User experiences were then investigated through a demo event to investigate the motivation, interest, social interaction, and suitability of the game concept for self-initiated physical training. User experience data was gathered based on researchers' observations and a questionnaire. This data was collected from users (older adults) and facilitators (social and health care professionals and students). The results indicate the game and the chair controller to be suitable and accepted by elderly as a mean of self-activation and physical training. The game concept also showed potential in enhancing social interaction in a group-setting. Although the responses from the participants show some variation, generally the results indicate feeling of usefulness and need for exergames. More research is required to investigate the long-term effects of the games on user experiences, physical/social effects, and potential decrease of fall risk.**

Keywords—physical ability; fall-prevention; older adults; recreation; self-managed rehabilitation; serious games

I. INTRODUCTION

Older adults form a large and increasing proportion of the population. With increasing age, the associated risk of falling or sustaining an injury because of a fall increases [1]. Considering approximately 30 % of individuals over the age of 65 fall every year, falls and fall-related injuries pose a major challenge within the society. It is estimated that following a fall, older adults are two to three times more likely to fall again within the following year [2]. Additionally, 20 % to 30 % of falls result as injuries that reduce independence and impair mobility. As an example, in Finland there are approximately 6000 hip fractures occurring every year (most are related to falls). One hip fracture is estimated to cost the Finnish government around 30000 €, in the year following the fracture alone [3]. Accordingly, this issue poses significant direct and indirect costs to the healthcare system.

Factors contributing to increased falls risk are multifactorial, often resulting from dynamic interactions of risks across several categories [2]. Potential risk factors can be identified as intrinsic factors, extrinsic factors, and exposure to risk. The intervention applied within this paper focusses on intrinsic factors, with a particular focus on impaired strength and balance.

With the emergence of smart furniture technologies, opportunities arise within the preventative health and rehabilitation sector. Amalgamating technology with game orientated exercise (exergames) facilitates the delivery of entertaining, complimentary tools in the provision of rehabilitation [4]. Furthermore, they may offer additional mechanisms for promoting and tracking adherence to rehabilitation. These tools may be utilised as an instrument to support existing rehabilitation processes and/or promote independent or remote rehabilitation.

II. FALL PREVENTION AND THE SMART CHAIR EXERGAME

A. Falls in Older Age and Prevention

Muscle weakness is a significant risk factor for falls in older adults, as is gait deficit, balance deficit, and the use of an assistive device. For the general population, a decline in strength and endurance is typically seen over the age of 30, involving a 10 % reduction in strength-endurance and 30 % reduction in power per decade. This loss of physical function creates increased difficulty performing activities of daily living (ADLs). As strength, endurance, muscle power, balance, and function declines, individuals find it increasingly more difficult to respond and recover from perturbations in centre of mass (i.e. experiencing reduced capacity to maintain and recover balance). Any lower extremity disability (loss of strength, orthopaedic abnormality or poor sensation) is associated with increased fall risk. In particular, difficulty in rising from a chair is associated with increased fall risk [2].

When considering intervention, exercise should be included as part of a multicomponent intervention to prevent falls in older persons [1]. Exercise intervention may take numerous forms, including strength, balance, gait, and coordination training. For high fall risk groups,

physiotherapeutic intervention may focus initially on strength and balance training in a seated or supported standing position, weight shifting and transfer training, and gait training, to target specific strength and coordination deficits. For moderate to low risk groups, physiotherapeutic intervention may focus more on dynamic balance and postural control, incorporating both the upper and lower extremity [5]. Exercise intervention can also employ the use of functional tasks, such as transferring from a seated to standing position (and vice versa). ADLs, such as sit-to-stand, are also commonly used to assess lower extremity function in relation to falls prevention. For example, the Five Times Sit to Stand (FTSS) examines an individual's ability to perform this particular ADL. As the name implies, the testee is required to rise from a chair and return to sitting five times as quickly as possible. This test aims to assess the mobility of elderly people living at home and in care services and is also suitable for evaluating Parkinson's disease and elderly with impaired cognition. More complex testing procedures, such as the Short Physical Performance Battery (SPPB), also utilise sit-to-stand within its three-part test to assesses balance in elderly persons [3].

B. *Exergame Concept*

The "smart chair" exergame developed for this study utilized three categories of minigames: ski-jumping, snowboarding, and ball throwing. These minigames, which are presented in Fig. 1, were selected to facilitate use by individuals with a range of capabilities. A winter sport theme was selected for the minigames, as they provide a familiar construct within the Finnish environment (where the exergame has been tested), thus potentially reducing cognitive loading during initial exposure to gameplay. These sports were selected to make the minigames more user-friendly, since most of the users are already familiar with these sports.

Fig. 1. Screenshots from the minigames a) ski jump, b) snowboarding, and c) ball-throwing.

Interaction with the game environment requires the user to move their body in relation to the "smart chair". For example, in the ski-jumping game, the player is required to stand up to initiate the jump and then return to a seated position when they wish to progress to the next minigame. The score is calculated by the distance the character gets to. To get a higher score, the user must time their jump correctly. The closer to the edge the user jumps, the longer the character will go, thus giving a bigger score. In the snowboarding minigame, the player remains in a seated position, leaning their upper body from side to side to interact with the game and make the snowboarder dodge obstacles. The user receives a score from touching collectable items on the slope. In the ball-throwing minigame, the player interacts with the game by throwing balls at targets that appear on the screen. To support use by individuals with a range of capabilities, some setting adjustments were incorporated within the minigames. The player or the guiding physiotherapist can change how fast the player has to react on standing during the ski-jumping minigame, how fast the snowboarder is going down the hill during snowboarding, and how fast the targets are appearing in the ball-throwing minigame.

The three minigames were designed to support intervention for individuals with varying physical capabilities. The snow-boarding minigame was designed to train postural control in a seated position. The ski-jumping minigame requires increased functional ability, with the player interacting with the game through performing a sit-to-stand manoeuvre. This was desirable, as the movements during the ski-jumping minigame (standing up and sitting down) resemble functional tasks performed within the FTSS and SPPB testing batteries. The ball-throwing game incorporates upper extremity strength and coordination and supports gameplay in either a seated of standing position. The ball-throwing minigame is best played with a large touchscreen, as it allows the use of soft balls instead of requiring the user to tap the screen.

C. *Exergame Platform*

The exergame was developed for Android devices. The games are compatible with phone, tablet, or a larger screen (like a smart TV that has an android operating system). The chair is connected to the Android device via Bluetooth.

The user's movements are measured through nine pressure sensors (FRS400), located under the cushioned sitting surface of the chair, and are designed to be unobtrusive. The nine sensors are wired up to an Arduino Mega, along with a Bluetooth module HC-06. The sensors send their analogue data to an Arduino that converts it into a readable format for the receiving device. It is also responsible for sending the data to the Android device. The Bluetooth module sends data globally, so no pairing of devices is required. To access the chair data, a connection is established from within the exergame. In the beginning of the game, the device lists all available Bluetooth connections where the correct device can be selected. The set-up used in the study can be seen in Fig. 2.

Fig. 2. The game set-up consisted of the smart gaming chair and the big touch screen (starting menu on screen).

III. Conducting the study

The exergames were played in a semi-controlled environment across two game events, one organized for seniors and another for social and health care students. The volunteer participants (N=29) were a) older adults (N=14) with an average age of 77.8 years (oldest 89, youngest 58), as well as b) students and their teachers (N=15) with an average age of 28.6 years (oldest 54, youngest 16). There were male seniors (N=2) and female seniors (N=12) as well as male students (N=2) and female students (N=11), as well as those who did not tell their gender (N=2).

In the first event, a senior group was first introduced to the games, followed by the senior test persons playing the games as other participants were watching. The researchers (N=3) were observing the game event to catch the authentic and intuitive reactions and comments. The observation themes were the same as used in the questionnaire, which followed the basic structure of Jesse Garret's user experience frame work [6], being: visual design, information and interaction design, functional specifications, and user needs. The same themes were used in the questionnaire, which the participants answered by circulating their answer. The propositions which were answered by: I disagree ☹; I somewhat agree 😐 and I totally agree ☺ were:

- Visual 1: The design of the prototype is good
- Visual 2: The outlook clearly indicated the use of the prototype
- Visual 3: The visual appearance of the prototype was good
- Info 1: In my opinion the prototype was easy to use
- Info 2: I understood the purpose of the prototype
- Func 1: The prototype functioned as expected
- Func 2: The functionalities of the prototype were sufficient
- Needs 1: If available, I would use the prototype
- Needs 2: The prototype is meaningful

The questionnaire also included a question related to test person's interest in modern technologies in general. This question was added to reflect the other answers. In addition, the participants were asked to rate the prototype by giving it 1 (worst) to 5 (best) stars. The participants were also asked to answer free questions, which were:

- How would you improve the prototype
- How would you use the prototype
- How did you experience the test event
- Any other comments

The questionnaires were given to the participants in the game event, so the participants could answer them at home. In this way, both authentic reactions (observations) as well as anonymous more carefully thought answers (questionnaires) were collected.

The same procedure was repeated with a social and health care students group (including physiotherapy students and practical nursing students as well as their teacher).

IV. Results and discussion

A. Findings, Observations

The observation concentrated mostly on the elderly participants. Generally, the prototype was well accepted and no negative attitude was noticed. The testing as such provided an enjoyable moment, where the participants could feel being part of technology development (free comments from seniors). Independently living people were extremely eager to comment and ideate improvements in the event. The game chair was well accepted as a game controller. One person addressed that the game chair was good for the back when sitting, and another was commenting the chair to be a nice model. The games themselves were relatively well understood and seniors were relatively willing to try the games. The ones not willing to try were still very interested in watching others play.

When it comes to social interaction, the games made people talk about winter athletes in general. Seniors were commenting to be interested in winter games and they talked about former athletes. As discussed above, multiple players were playing the "shoot the target game", which indicates potential in increasing social interaction. Games were bringing smiles to seniors faces, they were competing playfully, and few wanted to try again. Spectators were empathizing with the player and the players problems in the games. When one was playing, others watched and "played along" by for example leaning similar to the player. Others were also shouting advices to the players. In general, playing the games produced laughter, talk, excitement and even confusion (is the chair controlling the game?). Some comments were a bit contractionary. One player said that she did not understand how to play, but still she ended up being the seventh in the hi-scores. The ball-throwing game was the most popular one. This may be because the ball throwing is a familiar action and multiple players were trying at the same time. This is important to considered in future game development.

When it come to the meaningfulness of the games, common comment was the games to be good exercise. Many were also asking for the price and one comment was that "it is a shame that we will die before these will be in commercial use". The elderly residents commented "motion is medication", which indicated the thought of usefulness of the game increasing physical activities. Identification of healing as well as declining condition was also mentioned to be useful (game data could be used in this). Some of the care personnel said they would need this game to their workplace. Some persons thought that it would be a good idea to have a movable cushion with sensors, so that user could also play from the wheelchair. Comments such as "this could be a good exercise for breaktime at work or when waiting for doctor's appointment" were heard. One said humorously that "targets in the ball-throwing game could be for example doctor's picture, if the times are late". Another one commented "the game could be a good morning activity". In addition, the games recreational value was pointed out. However, also some concerns were noticed. Some people in wheelchairs or with rollators weren't as excited, probably because of the moving problems. Even some fears occurred that "this might be an addicting game". One older adult commented that "the technologies are more for future elderly".

The care givers were giving lots of free comments, which were in line with researcher observations. Two professional staff members asked the prototype for field tests. This indicate feeling of usefulness. Professionals were also pointing out that all the products should be marketed for all, not specially for elderly/specific user groups "MY solution" would be the added value (customizable product).

When it comes to the test event itself, it was challenging to show the prototype for elderly care residents, as there were a lot of assistive walking aid/wheelchairs. This must be taken into consideration in future test events. In addition, according to the observations, the seniors give a lot of feedback as they test the prototype. This is very important when it comes to collecting feedback. Authentic comments reveal a lot. However, it was also good to give questionnaires to home, so they would have time to think about things. Partial group interviews might also work as seniors were very eager to discuss. Everybody seemed to enjoy the test event. They would have stayed there longer discussing, if the bus ride would not be there.

Students were not the main focus of the observations, but generally speaking they were interested and discussing about the usefulness of the prototype. The students seemed interested when they watched the presentation of the prototype, but when they were to try, they were more shy (Finnish nature).

B. Findings, Questionnaire

The results from the questionnaires are presented in Fig. 3 – Fig. 5. In general, the feedback was positive or neutral in all the themes covered. This was also seen in the ratings. The average of stars given by the students was 3.9/5 and by seniors 4.5/5. One senior did not rate the game. It is also seen that both the seniors as well as the students were quite interested in modern technologies. Half of the students were very interested and 64 % of the seniors was very interested. Only one participant (senior) was not interested at all. This is a positive sign considering the development of care technologies.

The answers considering the visual design were also relatively good in both groups. When it comes to the information and interaction design, almost all participants understood the purpose of the prototype well. However, around half of the participants in each group gave only a neutral score to the ease of use. This indicates that further examination should be done to further improve the usability. Also the feedback related to functional specifications was mainly positive or neutral. However, as also the open questions reveal (discussed later), more games or additive functionalities were hoped for. This is seen in question Func 2 as some negative feedback (insufficient functionality). However, it also indicates the participant to be able to ideate other games and functionalities, which tells about successful technology knowledge transfer (side objective of the study was to tell about the possibilities of technology in order to get new development ideas from the participants). The developers got interesting ideas to further refine as discussed later. When it comes to the user needs, the students were slightly more positive on the meaningfulness of the prototype as none of the students considered the prototype meaningfulness. Also the seniors mainly saw the prototype meaningful (over half) or somewhat meaningful. Three seniors were thinking the prototype is meaningless to them. Most students and seniors would play or would consider playing again, if possible.

The answer to the open questions are in accordance with the answers to the proposition as well as the observations. When asking improvement ideas for the games, the researchers got various ideas. These were from seniors: "more games on the same platform, more instructions, different functions/control movement possibilities, sensors to be added in different kinds of chairs". These are from students: "add voice-controls, better graphics to games, more games, more group activities, more support when performing tasks, choosing a chair with less danger of injury, having a handrail or support in front/next to person to prevent falls, or having a softer surface; increasing options of games and tests (more chair exercising, sit to stand etc.), split-screen or online play to use it as a group/competition with friend, include video and audio, include remote control so that you don't have to stand up for start the game, more diverse games".

The students were able to give more feedback on paper, where as the seniors were more eager to comment during actual testing. The students might also be more aware of the possibilities that can be made to the games. However, the responses from both groups are extremely useful for the researchers for future development.

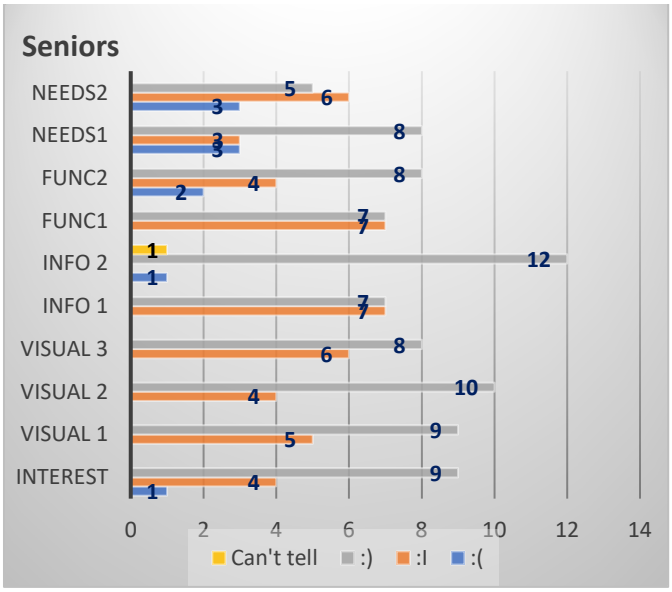

Fig. 3. Answers from seniors.

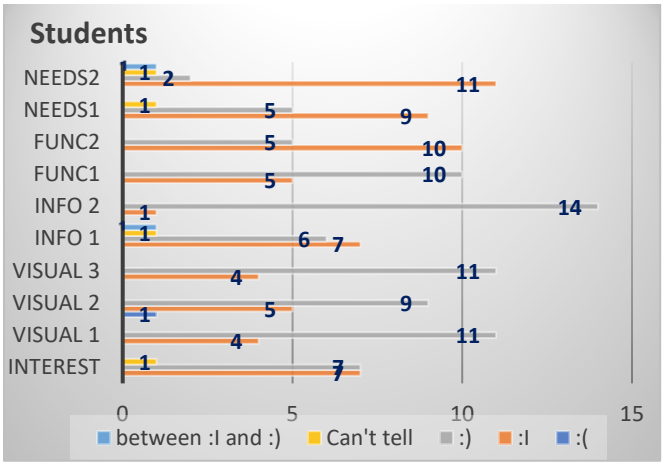

Fig. 4. Answers from students.

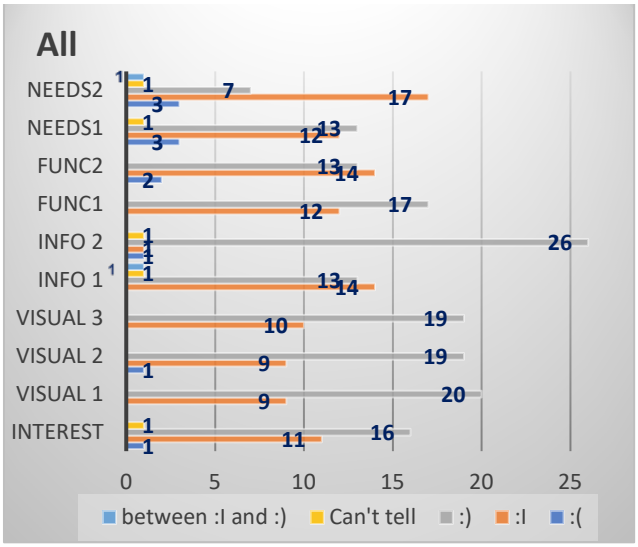

Fig. 5. All answers.

The answers for how to use the prototype, the answers from the seniors were: “I would play games and try other functions available as well (I’d like to explore what’s there), body training, concentration training, by the purpose, physical activation, physical exercise, rehabilitation, maintaining physical ability, recreational purposes, for playing, for my entertainment and for therapy”. The answers from the students included: “exercise for my own mom, in care home for recreational purposes, seniors, disabled, kids, everybody for rehabilitation, body training, concentration training, increasing activity, pleasure, therapy situations rather than home, monitoring improvement and doing tests, for neurological clients + elderly, home training for especially elderly but also others, physio practice: sit to stand test for clients on their own every time before consultation, for physios: create home programs and sent it to their smart chair program, activating the elderly, I would use it myself and also for my granny, for activation purposes for social and health care clients and for physical training”. From these answers, we can conclude the three main purposes ideated for the prototype were: physical exercising, social interaction, and recreation. These were also the main goals when developing the prototype. There might though be some bias, as the name of the prototype leads to thinking of physical training and elderly.

The event was described by the seniors: “enjoyable, fun, surprising, useful, interesting, fine, nice, and ok” and by students: “confusing, nice, super nice, interesting, useful, fine, good, ok and nice experience, I could have been player again!, fun and ok”. These answers together with the fact that most participants were interested in modern technology were encouraging and, in general the positive feedback and attitudes were one of the key findings related to development of care technology. This is even more empathized by the free comments from seniors: “I admire the smartness of the developers, it was quite an exercise, I liked that the prototype did not take much space, I could see this used in care homes (seniors + cognitively impaired, recreational activities), interesting event, opened eyes about future possibilities, help inclusion become reality, I’m grateful for the experience, this would be suitable especially in care homes”. The answers from the students considering further development were more constructive: “you must be quite fit to be able to play the ball throwing (bending to get the balls from floor), I like the idea, I would ease the ball-throwing game, I wonder, if the device is available for public, technology seems to be very helpful”.

C. Limitations

The main limitation in this trial was a relatively small test group, with a limited amount of data, which is why no far-reaching conclusions can be made. However, the results in this study encourage further testing and exergame development targeted for the elderly. Despite its limitations, this study provided parallel results to previous studies endorsing gaming as suitable means for self-managed activity combining physical, cognitive, and social elements to enhance older people’s well-being.

V. CONCLUSIONS

Exergames facilitate the delivery of entertaining, complimentary tools in the provision of preventative and rehabilitative intervention with potential to decrease risk of fall. In this study, a physiotherapeutic exergame based on a smart chair was developed. The suitability of the game for self-initiated activation of elderly was investigated through a simple user experience study. Generally, the results indicate positive user experiences and feeling of usefulness of the game concept as a mean of self-activation and physical training. The game concept tended also to increase social interaction. More research is required to investigate the long-term effects of the gaming.

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REFERENCES

[1] Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society. Summary of the updated American Geriatrics Society/British Geriatrics Society clinical practice guideline for prevention of falls in older persons. Journal of the American Geriatrics Society, vol. 59, no. 1, 2011, pp. 148-157.

[2] World Health Organization report, “What are the main risk factors for falls amongst older people and what are the most effective interventions to prevent these falls?”, 2004, 28p. Available online: www.euro.who.int/__data/assets/pdf_file/0018/74700/E82552.pdf

[3] S. Pajala et al., ”Kaatumisten ja kaatumisvammojen ehkäisyn fysioterapiasuositus. Hyvä fysioterapiakäytäntö”, 2011. Available online: http://www. terveysportti. fi/dtk/sfs/avaa.

[4] N. Skjæret, et al., ”Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy,” International Journal of Medical Informatics, vol. 85, no. 1, 2016, pp. 1-16.

[5] M. Fraix, “Role of the musculoskeletal system and the prevention of falls,” The Journal of the American Osteopathic Association, vol. 112, no. 1, 2012, pp. 17-21.

[6] J.J. Garrett, Elements of User Experience, The: User-centered Design for the Web and Beyond, London: Pearson Education, 2010.