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Balance Board-based System for Fall Prevention in Older Adults

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Abstract

The increase in quality of life over the past century led to the growth of life expectancy, which turns the population increasingly older. With this change, age related problems are more common. One of these problems is falling and its grave consequences. As age degrades biological elements that control body balance, falls become more frequent and more severe. Fall prevention programs usually integrate several complementary methods. One of them is exercise that improves balance in older adults, decreasing fall risk, but also strengthens the body, mitigating fall consequences. However, motivating seniors to do healthy exercises is difficult.

Recent affordable motion sensing devices have been shown to bring motivation as they turn physiotherapy sessions into entertaining and engaging interactive environments. One of those, the Nintendo Wii Balance Board System (WBB), uses four pressure sensors that measure the user's center of pressure (COP) which computation has been proved to be useful in helping the therapists evaluate their patient's balance. Many of these devices were created with entertainment purposes through exergames, which are video games where the player needs to do exercise to play. When oriented to therapy, exergames can be more motivating for patients than traditional rehabilitation methods.

The main objective of this dissertation is to study the relation between older adults and interactive exergames to provide a solution for their poor motivation towards regular exercise practice. In addition, the WBB capabilities are explored in order to evaluate the player's balance automatically through COP related metrics, which can help supervisors monitor patients. An alliance of game development techniques with fall-prevention exercises may motivate older adults as it combines the pleasure of playing video games with the need to promote balance.

Two interactive exergames were developed. These games require using the WBB to perform exercises that are part of the main fall-prevention programs, such as Otago Exercise Programme or Fitness and Mobility Exercise (FAME), and balance assessment scales as well, such as Berg Balance Scale. While the senior plays the game, the system uses the WBB capabilities to track the COP and compute balance assessment metrics used by physiotherapists, namely the COP's mean velocity and total oscillation. This data can be further processed and COP's path, amplitude over time and frequency maps can be generated.

The system was evaluated with two separate sets of tests with a total of 17 volunteers, in which they had the chance to interact with the games. Although most of them did not fully understand the games' mechanics and logic at their first attempt, all of them stated they enjoyed the experience, would like to play regularly and that the exergames motivated them to do exercise. The developed solution can hopefully lead seniors to increase the practice of physical activity and eventually decrease fall risk while providing physiotherapists a mean to monitor the evolution of balance of their patients.

Resumo

O aumento da qualidade de vida no século passado aumentou a esperança média de vida que levou ao envelhecimento da populção. Com esta mudança, problemas relacionados com a idade são cada vez mais comuns. Um destes problemas são as quedas e as suas graves consequências nos idosos. Como a idade deteriora sistemas biológicos que intervêm no mantimento do equilíbrio, quedas tornam-se mais frequentes e mais severas. Os programas de prevenção de quedas contém vários métodos que se complementam. Um deles é o exercício que melhora o equilíbrio em adultos mais velhos, diminuindo o risco de queda, assim como também o fortalecimento da massa muscular, atenuando as consequências das quedas. No entanto, é difícil motivar os idosos para praticar exercícios saudáveis de forma regular.

Foi demonstrado que equipamentos recentes e acessíveis que captam movimentos trazem maior motivação à fisioterapia ao tornar as sessões descontraídas e divertidas. A Balance Board da Nintendo Wii (WBB), usa quatro sensores de pressão que medem o centro de pressão (COP) de um utilizador e foi provado que é possível usá-la para ajudar terapeutas a analisar o progresso de um paciente. Muitos destes aparelhos foram criados para entretenimento, criando exergames que são jogos de vídeo em que o jogador precisa de fazer exercício para jogar. Orientados à terapia, exergames podem ser mais motivantes para os pacientes que métodos tradicionais de reabilitação.

O principal objectivo desta dissertação é estudar a relação entre seniores e exergames interactivos de modo a proporcionar uma solução para a sua falta de motivação para a práctica regular de exercício. É também pretendido explorar as capacidades da WBB para avaliar automaticamente o equilíbrio do jogador, através de métricas relacionadas com o COP para ajudar a monitorização dos pacientes. Uma aliança entre técnicas de desenvolvimento de jogos com exercícios para a prevenção de quedas poderá motivar idosos devido à combinação entre o prazer de jogar jogos de vídeo e a necessidade de promover o equilíbrio.

Dois exergames interactivos foram desenvolvidos. Estes jogos requerem o uso da WBB para realizar exercícios retirados de programas para a prevenção de quedas, como o Otago Exercise Programme ou o Fitness and Mobility Exercise (FAME), como também de escalas de avaliação do equilíbro, como a Berg Balance Scale. Enquanto os séniores jogam, o sistema usa as capacidades da WBB para seguir o COP e calcula métricas para a avaliação do equilíbrio usadas por fisioterapeutas, nomeadamente a velocidade média e oscilação total do COP. Com estes dados, é possível gerar gráficos de grande utilidade que podem ajudar terapeutas com a análise, que são o caminho, amplitude ao longo do tempo e mapa de frequência do COP.

O sistem foi avaliado a duas sessões de teste com um total de 17 seniores voluntários, onde estes tiveram oportunidade de interagir com os jogos. Apesar de a maior parte deles não ter compreendido totalmente a mecânica e lógica do jogos à primeira tentativa, todos afirmram que gostaram da experiência, gostariam de jogar regularmente e que os exergames os motivam para fazer exercício. A solução desenvolvida pode encaminhar os adultos para a prática de exercício regular e potencialmente diminuir do risco de queda enquanto ao mesmo tempo oferece aos fisioterapeutas um meio para monitorizar o equilíbrio dos seus pacientes.

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This dissertation is dedicated to my mother, for her strengths that never failed her when she needed the most. To my father for his support in any problem I encountered. To my sister to put up with me since I was born. To Diana, for accompanying me through this journey and whom I wish the best of luck for her new adventure. To Pedro, for his friendship and academic partnership. To all new and old friends.

Miguel Brito

"If I have seen further, it is by standing on the shoulders of giants"

Isaac Newton

Contents

List of Figures

LIST OF FIGURES

List of Tables

LIST OF TABLES

Abbreviations

AP	(Center of Pressure) Anterior-Posterior Direction
API	Application Programming Interface
BBA	Brunel Balance Assessment
BBS	Berg Balance Scale
CMA	Cumulative Moving Average
COP	Center of Pressure
EASY	Exercise Assessment and Screening for You
FAB	Fullerton Advanced Balance (Scale)
FAME	Fitness and Mobility Exercise (Program)
FIM	Functional Independence Measure
HCI	Human-Computer Interaction
ML	(Center of Pressure) Medial-Lateral Direction
NUI	Natural User Interfaces
TST	Tandem Stance Test
TUG	Time Up and Go (Test)
WBB	Nintendo Wii Balance Board

Chapter 1

Introduction

This dissertation addresses the study of using a digital game system for motivational home exercises to improve older adults' balance in order to prevent falls with possible supervision. Additionally, this document presents the state of the art and related work of the main related concepts of this dissertation.

Aging is a natural process, which every human being can expect to happen. However natural, this process brings unpleasant health problems such as muscle and bone weakening and body systems impairment. The combination of these and other age-related problems results on balance decay and aggravation of fall consequences [MF07]. Fall consequences in older adults can include hip fractures, hematomas and head injuries, among other problems, and can ultimately end in the person's death [MGB07]. Psychological and social consequences are also present. Fear of falling and post fall anxiety syndrome causes loss of self-confidence resulting in self imposed functional limitations [MGB07]. Naturally, falls also have economic consequences with health treatments, injury recovery and hospital stays costs which are higher with the increase of fall frequency [CR03]. Being falls one of the leading death causes [MGB07], fall-prevention in the elderly is of major importance.

Physical exercise is prominent when dealing with fall-prevention [MF07]. A combination of specific exercises regularly made, strengthens the muscles and improves balance, decreasing both fall risk and consequences at the same time [CR03]. With motivational techniques used such as positive reinforcement, exercise can also improve self-confidence in seniors. However, some older adults may not be receptive towards exercising. The reasons include fearing pain association, being injured and not having energy left for other activities that they consider more interesting. Addressing fall-prevention exercises motivation and make older adults understand their benefits is important to promote their practice.

The author believes that the wide success of the digital game industry is associated with its fun addressing capability and reality escape provision. With the technology evolution and new affordable motion sensing devices appearing in the market, developing exercise based digital games, called exergames, is now possible. Virtual reality and exergames can provide fun and motivation towards exercise [BSMN06]. However, commercial games are not fit to people with motor disabilities and adapting them to physical therapy is necessary [GVH+11]. This dissertation proposes the development and validation of an exergame for balance improvement and fall-prevention in the elderly.

1.1 Context

This work focuses on balance improvement addressing Fall Risk on the senior population. With the life expectancy rise, age related problems are more frequent as well. As previously stated, one of the most frequent and drastic problem is falls in the elderly. The mortality of falls increases dramatically with old age. Falls were the sixth leading death cause in persons with more than 65 years old and leading cause of injury related visits to emergency departments in U.S. in 2007 [MGB07]. Falls aftereffects in the elderly include hip fracture, subdural hematomas, serious soft tissue injuries and head injuries; in 2050, the estimated number of hip fractures is over 6 million [MGB07]. Besides physical damages, falls also cause psychological and social problems. Older adults may present fear of falling and, if already experienced a fall, post fall anxiety syndrome [MGB07]. These conditions result in loss of self-confidence and creation of self imposed functional limitations [MGB07] and lastly, the seniors stop doing leisure activities in which they used to take pleasure [MF07].

Fall causes can be of intrinsic or extrinsic nature. Intrinsic causes are normal age related changes, concurrent diseases (e. g. Alzheimer's disease or dementia), impairments in neurological, musculoskeletal, sensory and cardiovascular systems and cognitive changes (e. g. wrong environment risks evaluation) [MF07]. On the other hand, extrinsic causes can be poor lightning, slippery floors, lack of handrails (specially in the toilet and shower of tub), poor signage and certain medications such as psychotropics, antiarrhythmic, digoxin and diuretics [MF07]. Falls are often related to poor balance maintenance. Balance requires coordination between sensory, neurological and muskoskeletal systems which undergo deterioration over the years and consequently, may decrease balance [LMA07].

Various studies focused on fall-prevention. Mitty and Flores in [MF07] stated that staff and resident education towards fall-prevention, gait training, appropriate use of ambulation devices, medication review and exercise should be followed in order to prevent falls in an assisted living environment. Exercise is the only prevention method featured in the scope of this dissertation but the other methods should be taken into account.

MacCullouch et al. in [MGB07] point to exercise benefits for fall-prevention in the elderly. Exercise strengthens muscles and bones which not only improves balance but also attenuates fall's consequences. In addition, exercise might retard the biological process, alter positively consequences of diseases already present and also influence psychosocial functioning. Resnick et al. in [ROH+08] stated that exercise may also decrease coronary heart disease and stroke risk, prevent osteoporosis of the lumbar spine, increase gait speed and improve cognitive function in sedentary seniors and in those with dementia. Generally, adequate exercise improves quality of life [ROH+08].

Fall-prevention and physical therapy are closely related. Technology's presence in physical therapy is an important topic nowadays. As an example, biofeedback is used to give the patient performance awareness during the exercises and VR has been shown to have positive results when used in physical therapy [BSMN06]. In order to use VR systems in rehabilitation, these have to require and support tracking of user's movements. In Human-Computer Interaction (HCI), motion tracking is often associated with Natural User Interfaces (NUI) development. NUI goal is to be intuitive to use and composed by natural human movements. In order to NUI be possible, new devices were launched in the market and are now easily accessible for most people. Two examples of those are touchscreens integrated in smartphones and tablets, and body tracking devices such as the Microsoft Kinect[1].

Most of the described technologies were created focusing on entertainment and fostered the availability of digital games that require body exercises to be played instead of pressing buttons (i. e., exergames) for general audience. Nowadays, there are multiple examples of commercial exergames. One of the main purposes of exergames is to fight the sedentary lifestyle of gamers. This type of digital game has become well known and easily accessible for anyone in the past decade with the release of affordable devices such as Sony EyeToy[2], Microsoft Kinect and the Nintento Wii console[3]. The availability of these devices has made improvements in therapy possible by using them as instruments. For instance Kennedy et al. in [KSC+11] used the Nintendo Wii Balance Board (WBB) for balance rehabilitation exercises with positive results. The WBB is a device designed to interact with exergames by measuring the player's balance using four pressure sensors [LFC+10]. It was introduced as a component of the Wii Fit [4] game, where the main goal is for the player to do physical exercises to keep healthy.

This dissertation covers the use of game development techniques and the WBB in fall-prevention exercises implementation and their possible benefits.

1.2 Motivation

Digital games were shown to be important motivational therapy methods [GVH+11]. Nowadays, exergame devices are affordable to be present in every house which brings the possibility of having fun while exercise daily. Since their popularization, exergames oriented for healthcare are now a prominent area of studies. Deutsch et al. in [DBF+08] conducted a study to determine whether Nintendo Wii exergames could benefit physical therapy and the results were compelling:

[1]Kinect, Microsoft depth sensing camera, http://www.microsoft.com/en-us/kinectforwindows/

[2]EyeToy, Sony PlayStation depth sensing camera, http://pt.playstation.com/ps2/accessories/detail/item51711/C%C3%A2mara-USB-EyeToy/

[3]Nintento Wii, Nintendo game system that focuses in exergames, https://www.nintendo.pt/Wii/Wii-94559.html

[4]WiiFit, Nintendo game for Nintendo Wii, http://wiifit.com/

the patient shown motivation and efforts during the test and in the end obtained significant improvements. However, Geurts et al. [GVH+11] concluded that commercial available exergames were not fit for senior population and people with motor disabilities because the moves were too demanding. More detailed information about therapy oriented exergames can be found in section 2.3.2. Nevertheless, with the right type of exercises and calibration, exergames could be part of fall-prevention.

Elderly adults found pleasure using a NUI with Nintendo Wii controllers despite lack of technology known-how and physical limitations [BP09]. By introducing fun factors in treatments, the patients have a pleasurable experience and tend to exceed themselves in both exercises duration and effort in comparison with traditional rehabilitation methods [DBF+08]. Relaxing environments provided by exergames may promote user's motivation which is critical for treatments success. Therefore, exergames may also offer elderly adults motivation and will towards exercise and, consequently, decrease fall risk.

The WBB has been shown to be a useful balance therapy instrument as well [BBKO11, KSC+11]. The WBB has four pressure sensors and can calculate accurately the user's centre of pressure (COP) and weight. This data that can be used to compute COP path length and velocity where balance assessing force plates cannot be used due to its high cost and size [CBP+10]. This way, measuring patient's balance and keeping track of his progress can be done during the session without reducing therapy time [KSC+11]. As many exergame devices nowadays, WBB is affordable and commercially available to general public. In this scenario, new ways of rehabilitation mechanics are being study to motivate people to therapy or exercise programs and make it more effective. However, there are no major solutions in the market yet.

In this work, exergame's benefits for senior population and how they embrace this new exercise method are studied in order to improve balance and prevent falls.

1.3 Problem

This dissertation focuses on a specific approach for prevention of falls, whose frequency and consequences were described in subchapter 1.1. Both physical and psychological consequences lower older adults life quality. Exercise is a fine prevention, defense and self-motivating method, however, there is lack of adherence by seniors [MF07]. They may think exercise is for young people and fear pain associated to the movements, being injured or not having energy to do other activities [MF07]. Repetitive exercises may be one boredom cause [MF07] but repeatability also make seniors feel more secure and less stressed [EDP06]. As the benefits of an exercise program are dependent of ongoing commitment of the participants [CR03], acknowledging their progress and introducing harder exercises gradually is important [EDP06]. Nawaz et al. have shown that older adults can have fun with exergames [NSrY+14], thereafter, one way to do this could be with an abstraction of fun exergames with different levels.

Therapy data collection is addressed as well. Manual data collection steals valuable time from the therapist that could be used more efficiently. In the age of technology where everything is stored digitally and intelligent systems are created every day, data automatically collected from the instruments used for addressing rehabilitation is plausible.

Allying game development techniques with rehabilitation can motivate patients to therapy. Therefore, the research statement of this dissertation is:

> *Supervised home exercise through the use of exergames is motivating, has benefits and is practicable to decrease fall risk.*

The statement claims that exergames could be motivating enough to lead elderly adults towards physical activity. With the use of fall-prevention specific exercises, exergames should be able to offer the same benefits as physical activity and therefore, decrease fall risk. With supervision provided, the game session can be customized to each person in order to address their situation and chose the exergames more fit to their needs.

Deriving sub-research statements from the previous main research statement is possible:

- Elderly people do exercise longer and with more effort when faced with exergames instead of more traditional ways.

  Little to no exercise has no benefits. Exercise session should last about 30 minutes [ROH+08] and repeated two or three times per week [EDP06]. Exergames may provide elderly adults the motivation to reach these conditions and take full advantage of fall-prevention exercises.

- Elderly people feel more self-confident during and after a session of exergames playing.

  Self-confidence is important to overcome psychological limitations that prevents older adults to perform activities they want to do. Boosting self-confidence is important to give independence to seniors and increase their quality of life.

- Automatic balance measure is computable and consistent.

  Measuring balance while seniors would play exergames could provide them feedback concerning their fall risk. Further developments would allow therapists to measure balance at the patient's home, not being limited to their clinic. Finally, therapists or caretakers distance supervision is applicable while user's practice exercise at home.

In this dissertation fall-prevention techniques will be researched in order to approach the problems raised by these statements. Fall-prevention exergames can be a market opportunity for digital game companies and can be played at home or in an assisted living community. The next subchapter, 1.4, describes the required steps to validate this hypothesis and chapter 3 describes the solution implementation and validation proposal.

1.4 Objectives

In order to verify the research statement described in the previous subchapter, 1.3, the following objectives are proposed for the scope of this dissertation:

- Develop an exergame application fit to be played by elderly people and with specific exercise movements to prevent falls;
- Implement balance assessment with automatic metrics used by physiotherapists to provide a mean to monitor the player's evolution;
- Evaluate the elderly adults' motivation to exercise with the use of the developed application;

The exergame application is a level based digital game where the player must perform one or multiple of exercises to control the character and solve the problems. Problem solving levels and game rewards are important as they were shown to be effective to motivate patients for therapy sessions [BSMN06]. The exercises were chosen from main used fall-prevention exercise programs to hopefully improve older adults balance and decrease fall risk.

While the user plays the exergames, the system keeps track and records the player's COP. This data can be used to assess the senior's balance or fall risk and to draw charts with the COP progression, e. g., COP's path, frequency map over time and amplitude over time. These metrics could be useful to diagnose a person's balance at a distance without having to travel to a medical facility. The system development is described in chapter 4.

Regarding the evaluation of the concept, user studies took place with a group of seniors where they experienced the developed games. They were be asked for a background about exercise practice and questions about their gameplay experience. Chapter 5 describes these tests and respective results.

1.5 Contributions

In this dissertation's scope, the following contributions were given:

- Automatic balance measures computation framework, which includes several metrics, was implemented that enabled assessment during exergaming gameplay;
- Two exergames were developed that require exercises taken from fall-prevention exercise programs and balance assessment scales;
- The project was tested in two separate sets with a total of 17 senior volunteers where they had the opportunity to interact with the games;
- A poster and a demo papers were submitted to ACM ASSETS 2015 conference, one of the main conferences in using technology to improve accessibility.

The system development, including games and balance assessment, are described in chapter 4 and the tests in chapter 5. Relatively to the papers, the poster focuses on the results while the demo on the games development.

1.6 Document Structure

This document is divided in five more chapters as follows:

- Literature Review, chapter 2, documents the author's topics literature research and the actual state of the art details, namely: a brief overview of balance rehabilitation, HCI, exergames health contributions of these topics.
- Implementation Proposal, chapter 3, describes the solution approach to the problem, its architecture, and different exergames proposed to be developed.
- Development, chapter 4 describes the exergames implemented and the exercise automatic evaluation and data collection.
- Chapter 5, Evaluation and Validation, presents the tests in which the project was subjected and respective results and analysis.
- The last chapter 6, presents the author's conclusion about this work and further development.

Chapter 2

Literature Review

This chapter presents a brief history and state of the art of the dissertation main concepts. It presents related work in the fields of HCI and exergames oriented to therapy in order to identify what steps one should or should not take, making clear the project's scope and the gaps it pretends to fill.

2.1 Balance Rehabilitation Overview

Rehabilitation is the first step in overcoming balance disorders. Although not entirely necessary for fall-prevention in the elderly, balance therapy gives a head start in beneficial exercise research and patients progress evaluation. This subchapter describes balance evaluation in section 2.1.1 and exercise programs for older adults in section 2.1.2.

2.1.1 Balance Assessment and Measures

Balance maintenance requires coordination from sensory, neurological and muskoskeletal systems [LMA07]. Commercial force plates are used to compute a person's COP while standing. These devices can be used to identify older adults with higher fall risk even when there is no evidence of a balance impairment [PEK+08]. With the COP values over some time, one to two minutes, several variables can be determined for balance assessment [DF10]. COP can be measured in two axis: in the anterior-posterior direction (AP) or backward and forward, and medial-lateral direction (ML) or side-to-side. The most useful metrics are the stabilogram's bandwidth and the COP path, medium velocity, oscillation area and total displacement [DF10]. Higher COP bandwidth, alongside inability to tandem standing[1] and higher body mass index, indicates higher probability of a fall occurrence due to intrinsic factors [PEK+08]. The COP test should be done two to four times as too many repetition may cause fatigue and learning, which can result in a wrong analysis [DF10].

[1] Stand with a foot in front of the other with the front foot's heel touching other's toe.

Laboratory testing of balance using treadmills or sway platforms is impractical in most clinics [PR91]. Therapists nowadays use subjective scales thoughtfully tested based on functional balance tests. Functional balance tests are exercises based on basic movements such as getting up from a chair, standing or picking up objects. Using this type of tests has advantages for their low cost, lack of complex equipment and time efficiency [LMA07]. Those should be a test compilation that have to be challenging to all the systems involved in balance maintenance and tools used to measure have to be sensitive to changes in the elderly in order to make the assessment accurate [LMA07]. A reliable scale must provide similar results when performed on the same person, under the same circumstances evaluated by different raters [LMA07]. The gold standard scale for balance assessment is the Berg Balance Scale (BBS) [LMA07].

BBS is a series of fourteen exercises focused on the ability of maintaining balance when asked to perform some challenges [BWDWG89]. Some examples of these exercises are standing in various conditions such as with feet together or with eyes closed, retrieving an object from the floor, changing from seated to standing position or stool stepping. The evaluator grades the patient's performance in a scale from 0 to 4 for each exercise. In the end, if the total sum is from 0 to 20 then the patient's balance is considered poor, from 21 to 40 is fair and otherwise it is considered good [BWDWG89]. The BBS test lasts around 15 minutes and requires a stopwatch, a step, two chairs and a 40cm ruler [LMA07]. Field studies revealed consistence between grades given by different therapists for the same set of patients [BWDWG89].

The Time Up and Go test (TUG) shown high correlation with BBS [PR91]. The TUG consists in getting up from an arm chair, walk three meters, turn, come back and sit in the chair [PR91]. Evaluation is given relative to the time the patient takes to complete the task. Patients who take less than twenty seconds were shown to be independent for basic mobility activities whereas those who took more than thirty had difficulties getting up of bed, sitting and getting up of a toilet and getting in and off a tub [PR91]. TUG is a reliable test to assess patient's balance, gait maneuvers and functional abilities and track physical mobility deterioration [PR91]. However, TUG does not give enough information to detail the source of balance impairments [LMA07].

The Fullerton Advanced Balance Scale (FAB) was created in order to assess older adults who live independently or do most of their daily activities by themselves as the BBS was limited in this group of people [RLW06]. The FAB test consists on 10 exercises more challenging than those of the BBS and rated in the same fashion, grades from 0 to 4 [HR08]. This test takes from 10 to 12 minutes to complete and can be performed in the patients house or in a small clinic [RLW06]. The required materials are a stopwatch, a pencil, a 12 inch rule, a 6 feet high bench, a masking tape, two foam pads, two 18 inch length non slip material, a yardstick and a metronome [HR08]. The tests revealed that FAB is reliable and correlated with BBS scores [RLW06]. Hernandez and Rose shown that a 1 point decrease in FAB final score means an 8 per cent increase in fall probability and 70 per cent of older adults who score less than 25 have high fall risk and should start fall-prevention therapy [HR08].

The Brunel Balance Assessment (BBA) is another set of functional tests created to measure the effects of rehabilitation or changes over a short period of time whereas the BBS lacks sensitivity

[Tys04]. The BBA has three sections of exercises: sitting, standing and stepping. The BBA tests are hierarchical. This way, testing can start at a level reasonable for each patient. For instance, for a patient that can walk, the therapist can assume that he can overcome each sitting test [Tys04]. The patients perform each exercise until they get to the level of their limitation. If the patient cannot achieve the minimal requirements of a level after three attempts, test should end and the score from this level can be used as a performance measure [Tys04].

Another metric used when assessing balance is the Functional Independence Measure (FIM) [KSC+11]. However, FIM is more practical when used to access the dependence care a frail person needs. Nevertheless, subsets of FIM can be used to access certain conditions, e. g. stroke which is a cause for poor balance [SJFG97]. FIM assessment is composed by 18 exercises, which can be divided in two sets:

- Motor capabilities which include self-care limitations, sphincter control and mobility and locomotion functions;
- Cognitive capabilities which include communication and social functions.

These sets can also be divided in other sets to better evaluate a person condition [SJFG97].

2.1.2 Exercise Programs for the Elderly

Different exercise programs have been created and successfully tested regarding fall-prevention. In New Zealand, Campbell and Robertson's Otago Exercise Programme has decreased fall frequency by one third in four trial tests and improved senior's self-confidence for daily activities [CR03]. This program is based on home exercises prescribed by a physiotherapist in regular evaluation visits. The sequence of exercises should be repeated three times per week and be accompanied by a weekly walk, which can also be planned by the physiotherapist. Otago's authors encourage older adults to walk more in their daily activities instead of driving and leaving public transports in the nearest stop and visit friends instead of chatting with them over the phone, although walking alone has few benefits [CR03].

Another exercise program that obtained successful results was the Fitness and Mobility Exercise (FAME) program [EDP06]. This program was developed for exercise group session for fall-prevention on people victims of stroke. Participants stated that group exercise was motivating and socially stimulating resulting in better adherence to the program and countering depression [EDP06]. FAME authors attribute importance to socialization and fun encouragement, for instance by congratulating someone on having another grandchild during the session or having snacks after it, in order to further increase adherence and motivation.

FAME program addresses multiple domains: balance, muscle strength, bone health, mobility, cardiovascular fitness and depression. Sessions are hold two or three times a week each lasting for about one hour. Participants may perform the exercises by themselves or with help of a family member or an assistant. Instructors should also check for fatigue and pain regularly and be familiar with stroke in case some participant starts showing symptoms. Participants with bone diseases such as osteoporosis or osteopenia should be restricted from spine flexing and twisting exercises.

Three trials have been made to test the FAME program. The first one lasted eight weeks, the second ten weeks of program and one year of observations and the third lasted five months. In all trials it was observed improvements in walking endurance and mobility and fall risk decrease. In addition to that, the first trial participants had less pain and improvements in leg muscle strength, daily activities performance, energy levels and self-perceived quality of life. The second group achieved faster postural reflexes (i. e. reflexes to recover from a fall) and 30% less falls in participants who had fallen previously. In the third trial there were two groups: the FAME group who performed the FAME program and a control group who did some weight-bearing and stretching exercises. Bone density was maintained in the FAME group where it decreased in the other group. The FAME group also obtained improvements in cardiovascular fitness unlike the control group [EDP06].

Another exercise program is the Exercise Assessment and Screening for You (EASY) [ROH+08]. EASY is a Web tool where the purpose is to help older adults, healthcare providers and exercise professionals identify exercises and physical activity for the elderly that meets their existing health conditions, illness and disabilities. It is based in a questionnaire of 6 questions that identifies possible health conditions the senior may have. With these symptoms collections, the tool's algorithm forwards the user to a set of exercises he can do safely. In addiction, if it detects some serious condition, EASY will recommend to clarify the possible exercises with the user's healthcare provider in order to avoid a exercise related injury or cardiovascular event. EASY also provides safety tips that it highly recommends the seniors to read thoroughly so they can fully understand exercise risks and signs and symptoms of injuries and health conditions and this way learn when to stop. Lastly, EASY recommends exercise sessions of 30 minutes on most days of the week if not all days, unless the senior is not used to exercise. In this case, he shall gradually increase the session time until he reaches 30 minutes sessions [ROH+08].

Melo [Mel08] designed an exercise program based on literature in order to study exercise outcomes in elderly population. The proposal was a home exercise based program, with specific items for ankle flexibility, lower limb strength, balance and voluntary stepping time improvement and without the need of extra equipment. The program was tested with a randomized controlled trial approach during nine months. The intervention group shown significant improvements in several balance measures in comparison with the control group [Mel08].

Seguin et al. [SEB+02] published an exercise program for older adults with recommendations for keeping motivated and eliminate obstacles to exercise. The presented program is safe, simple and highly effective [SEB+02]. The program pretends to held seniors to build strength, maintain bone density, improve balance, coordination and mobility, decrease fall risk and maintain Independence in daily life activities. The author's advise the user to set up goals and celebrate the achievements in order to keep motivated. If there is a health concern or condition, the seniors should discuss the program with their doctors.

All the previous exercise programs state the importance of warm-up and cool-down exercises in order to avoid exercise related injuries, namely muskoskeletal minor injuries [ROH+08], and concerns about the patients safety as well.

2.2 Human Computer Interaction

In the beginning, HCI main goal was to make humans more efficient while using a desktop computer. Nowadays, HCI combines various sciences, such as psychology, sociology and anthropology, to study how we interact with technology and what emotions it arouses in us, not only at work but in home life, education, entertainment and so on [SRHR09]. HCI studies our relation with technology. With technology evolution, Sellen et al. in [SRHR09] identified two important changes in this relation: *the growth of techno-dependency* and *the end of interface stability*. The first compels the presence and dependency of technology everywhere: in business, in schools, in hospitals, public transport systems, etc. The second denotes the new ways of interacting with technology with recent sensor composite devices such as smartphones, Microsoft Kinect and Nintendo Wii controllers. These devices provide motion sensing which can be used to create gesture-based interfaces.

2.2.1 Ageing and Human-Computer Interaction

Vines et al. [VPWO15] elaborated a critical analysis of over 30 years of HCI research for the elderly with the goal of finding its main concerns and give advices for future studies. They identified four main discourses in HCI publications and give four recommendations for future research.

The first concern is treating ageing as a social economic problem with negative impact expected to everyone, including high disease risk, high medical assistant need and cognitive skills decreasing. With this assumption, researchers and funding institutions invest in developing system to help "reduce the risk of growing old" [VPWO15]. This means health-care research money is being applied in technologies for the later life focusing on reducing risks factors associated. These investments led to less funding available to projects in other areas, such as psychological and behavioral sciences. This scenario creates the idea that ageing is undesired and should be avoided. According to Vines et al., in order to avoid this characterization of ageing, researchers should "critically reflect on where the underlying motivation for studying ageing comes from, and challenge any taken for granted assumptions and predominantly negative societal attitudes of ageing". This means that, while health and wellness issues are important, HCI researchers should not ignore other gerontology areas.

The second main concern is tackling social isolation risk of older adults. Elderly adults are more exposed to isolation, particularly if they live alone of in a residential care facility [VPWO15]. This loneliness is sometimes not expected by researchers. Seniors lack engagement when interacting with technology but have great pleasure when connect with someone over the Internet [VPWO15]. Recent studies approach this concern, developing systems with new possible interactions with other people through technologies.

Third discourse is the generalization of older adults population where researchers characterize them in a homogeneity way. This generalization is present when studies compare HCI usability between younger people and elderly adults and when the population is defined as retirees or grandparents and details about their past, such as education or jobs, are omitted [VPWO15]. This generalization may hide common problems in older adults with determined characteristics. To tackle this, Vines et al. challenge researchers to engage personal experiences and how they affect user interaction into their studies. Taking in account senior's life experiences can be helpful to acknowledge what would drive the user to interact with technology, develop a better experience and at same time avoid characterize a population with common issues related to their age when it may be untrue [VPWO15].

Finally, the last discourse is the technology impairment present in most seniors. This population did not grow up surrounded by technology as opposed to younger people. In addition, many suffer cognitive and physical changes, which turns theirs interaction with technology a challenge. For this, Vines et al. recommend engaging with older adults prior to the design process and also to support an agenda shaped by them in order to understand their needs and this way, redefine research questions that can provide a "successful ageing" [VPWO15]. Here, success can embrace more than being physically and mentally healthy, for example feelings of society worth, relationships or simply having time for activities one enjoys the most. This way, the negative stereotype of growing old is also diminished.

2.2.2 Natural User Interface

NUI offers a practical interaction to people not used to keyboards and mouse [BP09]. Elderly adults enjoy interacting with Nintendo Wii controllers and find them useful for therapy despite technology and physical limitations [BP09]. These devices provide transparency and sense of power and control when machines do what people want from their movement readings [vB12]. Although keyboard an mouse offers better performance, gesture interaction is funnier, easy to use, natural and makes user's involved in their tasks [vB12]. However, it also causes more fatigue, recognition errors from movement, e. g. users scratching their nose, and has low accuracy [vB12]. Wii controllers provide better performance without having additional cons [vB12]. NUI is now a salient area in entertainment, artificial intelligence, simulation, training, education and assisted living [BP09].

Nielsen and Störring [NS03] proposed a method to create an interface with hand gestures. First, developers need to define the project's context and the functionalities. Then, they study gestures end users do when talking about those functionalities with other users. Finally, interaction designers analyse the collection and choose the fittest gesture for the functionalities and test them with guessing functions from gestures, memory and stress tests with end users.

2.2.3 Human Computer Interaction in Balance Therapy

Recently, Clark et al. shown that the WBB can be used in clinics to compute quantitative balance measures, namely center of pressure path length an velocity, with high correlation with precise commercially force plates that are the gold standard in quantitative balance measurement [CBP+10]. González et al. developed a Center of Mass estimation system which uses the Kinect and the WBB using the statically equivalent serial chain method [GHF12]. The solution is a portable and affordable alternative to other systems despite its limitations. Improper light, loose fitting clothes and large objects surrounding the user interferes Kinect readings while WBB area limits the number of poses the user can make [GHF12].

In 2011, Kennedy et al. [KSC+11] studied the benefits of WBB in physical therapy, creating a rehabilitation system called WeHab. The WeHab provides real time information about the exercise and the performance, namely COP, to both patient and therapist. COP is displayed to patients so they can feel more motivated with an objective analysis instead of the therapist feedback. Therapists felt it was benefic to have the WeHab data instead of relying only in their visual assessment and in the end they made a better progress analysis. The results of the study show the patients obtained a higher FIM score after four weeks. The Wehab also collects data and analyses it but the results were not consistent with the final FIM score of the patients [KSC+11].

Ayoade and Baillie [AB14] developed a knee rehabilitation system to be used in home rehabilitation replacing the traditional method that consisted in giving patients a handbook and a DVD with the exercises. This method is not considered ideal because it is repetitive, boring and lacks interactivity which leads to low adherence and, consequently, poor rehabilitation outcomes. Ayoade and Baillie's solution consisted in two motion sensors that sends data to a laptop. This laptop guides the session showing the ideal exercise movement, giving feedback about them to the user and counting repetitions. It also can be used in videoconference with the therapist. Six week trials caused greater knee flexion and extension improvement on patients using their system in comparison to patients who used traditional methods [AB14]. The authors stated that the improvements were possible due to real time feedback, which permitted users to do the movements more correctly and gave them confidence, and increased motivation in the rehabilitation beginning. However, motivation decreased in the end as exercises were considered too easy in this phase [AB14].

From their study, Ayoade and Baillie concluded the following factors to be important while developing home rehabilitation applications:

- Safely encourage correct performance towards the rehabilitation goal and expected improvement over time;
- Count exercise repetitions;
- Record a progress history;
- Display the essential movements parameters and show the ideal performance;

- Intuitive interaction;
- Satisfaction of the target population.

The first item means that the system should give correct feedback about his exercises and to demand more effort from the patient while he progresses. This will make the user understand if the exercise is done correctly or not as the traditional method has no guarantees. In addition, it keeps the user motivated to do better while no added difficulty will make him bored. Count exercise repetitions helps patients to do the expected amount of exercises without concerning to count allowing the user do focus on his performance. Progress history reports users of their timely evolution. The fourth item is also important for users to understand what movements should they do and to observe rehabilitation goal results. Having an intuitive interaction and user satisfaction is also important as they motivate patients to use the applications and consequently, improve rehabilitation outcomes.

2.3 Exergames

Most recent devices described in the last subchapter 2.2 were create towards entertainment, making exergames accessible for anyone. Nowadays, health oriented exergames benefits are thoroughly studied as they can create fun and relaxing environments for people which is a key factor in treatments success.

2.3.1 Enjoyment in Exergames

Digital games can provide enjoyment to people. Here enjoyment means an individual's positive response towards technology and its context. Experience enjoyment is the main reason why people play games [MBTO14]. The game flow is a very important component assessing game enjoyment. Game flow is a subjective experience of engaging in challenging but still manageable activities, complete cognitive absorption and time distortion [MBTO14]. A difficult game for a novice player can create anxiety making him quit while a very easy game can cause boredom. Increasing challenges difficulty as the player progresses and gains skill is then important [MLB13]. This way, fun can be achieved throughout the whole game.

However, game flow does not cover all the enjoyment a digital game can give [MBTO14]. Game style factors can be determinant when providing enjoyment to players. Fantasy inclusion, narrative, avatar resemblance and player's identification with it, other playable characters, sound and music effects, high quality realistic graphics, use of humor, character development over time and game medium duration (few days or weeks) affects the way players feel about the game [MBTO14, MLB13]. Psychosocial characteristics also affect the way a person enjoys a game, it depends on the player. The most important players traits are sensation seeking, self-forgetfulness, desire of being in control, self-efficacy and need of satisfaction (mood repair or recovery of an experience) [MBTO14]. Games that cause guilt, e. g. violent games for some players, are not effective to provide enjoyment [MBTO14].

Physical activity creates body responses that also promote enjoyment [MLB13]. Then, combining digital game enjoyment with physical education enjoyment should result in exergame enjoyment. This does not mean that exergame enjoyment is easy, enjoyment in exergames must be assessed in the same way as a digital game.

Enjoyment is important and commercial exergames are oriented to it. However, they lack quality feedback on the players movements as they accept a wide range of motion to accommodate a more varying audience [ZW14]. This increases injury risk and creates a false sense of confidence [ZW14]. Zaczynski and Whitehead studied how to increase exercise correctness and player's confidence through the use of various feedback forms in [ZW14]. They recommend the following design guidelines for exercise games:

- Provide visual demonstration in multiple angles instead of only one view to help understand better the movements requested. However, too many angles may cause cognitive load increase, which does not help the players.
- Add verbal instructions to demonstrations to increase comprehension as some movement components may be "hidden" to the player and other actions can help players, such as breathing moments.
- Clarify orientation environment in the demonstration's beginning. For instance, players can lose entire demonstrations if they do not understand which hand or foot to use. Therefore, developers need to guarantee clear instructions. This becomes more important as more complex the exercise is.
- Use verbal delivery as a supplement keeping users focused on visual demonstration. It was observed that the use of directions left and right often leads to confusion. Visual demonstration should remain the point of reference while verbal description provides analogies and "hidden" details.
- Provide custom and contextual feedback to help player's correct themselves instead of inform them that they are doing the exercise wrong.
- Give visual and verbal feedback for users to notice it in any position. If possible, also use haptic feedback for a better understanding of what they are doing wrong.
- Understand and be aware of the player's capabilities, specially in training and rehabilitation. Understanding the user is essential to help him, otherwise we could be asking impossible movements for him.

These guidelines are useful to develop exergames for different players in different areas such as yoga or physical rehabilitation and fall-prevention.

Nawaz et al. [NSrY$^+$14] studied how to access user experience in seniors in order to describe guidelines for exergame development for the elderly. They pointed the following topics should be addressed:

- Benefits expected by patients when playing the game;
- Clear feedback to help players do the right exercise;
- Social interaction in games by introducing multiplayer modes;
- Suitable and safe exercises to play;
- Easy interface interaction and set-up to seniors;
- Progression in the game by game score and harder levels;
- Use of the native language where the game is played.

These guidelines reflect the lack of confidence of older people when using new technologies. Motivating them to use new technologies is as important as motivating them to play exergames, otherwise, possible benefits are reduced.

2.3.2 Therapy Oriented Exergames

Affordable devices and exergames appearance raised questions about the possibility of using of digital games for rehabilitation therapy.

Deutsch et al. in [DBF+08] made a first approach to the use of Nintendo Wii console in physical rehabilitation. An adolescent student with spastic diplegia cerebral palsy was subjected to eleven sessions during four weeks where he would play Wii games from a set of four games and the patient was given the liberty to play each game for how long he wants. The therapist observed that while playing the digital games, the patient did not feel he was in therapy and did more effort in the exercises. In the end of fourth week, improvements were observed in almost all the aspects of visual perception, postural control and functional mobility. Deutsch et al. also stated that the patient was engaged in all the sessions. However, in the eighth session, there was a declination of the patient's motivation, which was successfully overcame with the introduction of another player.

Lange et al. [LFC+10] developed an exergame for neurological injury rehabilitation using the WBB. The game consists in levels where the player has to control a balloon shifting their weight in the directions they want the balloon to move in order to avoid obstacles. This game was tested in a clinic and the patients reported that they had enjoyed the experience, felt that they did better than in therapy sessions and would like to do it more often. The therapists stated that the game was great to patients as a training tool and the sense of achievement given to players was important.

More recent works indicate important factors to be considered to develop motivational rehabilitation exergames. Geurts et al. in [GVH+11] concluded that it was important to be possible to calibrate the exergames according to the patients' needs and capabilities. Patients are different from each other and without calibration, the patients with more difficulties will not experience the same sense of achievement, fun and motivation. Geurts et al. developed four adjustable mini games for different therapy exercises for people with spasticity using commercially available input devices such as the WBB. They tested prototypes of these games with therapists, which confirmed that the games were fit for using in therapy and the input quality was sufficient.

Recently, researchers investigated how to address exergaming to older population. Uzor and Baillie [UB14] developed five exergames for seniors and wireless inertial sensors to interact with them. These sensors detect the nine movements, four of those are used in each game, which are: sit-to-stand, side steps, marching, knee bends. These games were submitted during 12 weeks to a group of eight seniors who were given a booklet and a video of the Otago Exercise Programme. A group of nine other seniors were given the same booklet and videos. Adherence and motivation to exercise and balance benefits were compared in both groups. This study suggests that elderly adults are more engaged, do more effort and exercise more often while playing exergames than without them. Exercise benefits improvement was not possible to be observed, as the test duration was short.

Davies et al. [DDS+13] developed two exergames for balance training that use the WBB as interaction device. Those digital games were tested with a group of 5 seniors who have done occupational or physical therapy before. All seniors claimed that the games were as strenuous as therapy exercises but more engaging. The game collects the player's reaction time and raw data from the WBB. However, the author concluded that it was hard to monitor the player's performance with this data due to the game's nature, which requires random COP's trajectories to progress, and the many ways the user can manipulate the COP's position.

2.4 Technologies

In this subchapter game development technologies are discussed. The objective is to identify the most efficient and practicable engine for game development in the present and also how to communicate with the WBB to allow speeding up development in a consistent and secure way.

2.4.1 Game Development Tools

Game development engines have become popular due to their abstractions towards digital game architecture, many of them offering standard base assets as game physics and character control. Table 2.1 was taken from PixelProspector[2] website summarizes the features of the most popular game development engines nowadays.

Developing digital games with higher abstraction layers allows game designers to quickly and without a large expertise implement a game. However those features remove game customization, which can be important to implement artificial intelligence, and network and different device support.

The most complete engine in table 2.1 is Unity[3] that offers both two and three dimensional support and cross-platform target devices. Unity is a widely used technology in the present and

[2]PixelProspector, blog about indie game development, http://www.pixelprospector.com/the-big-list-of-game-making-tools/

[3]Unity3d, game development framework, http://unity3d.com/

Table 2.1: Game development engines from website PixelProspector.

Engine	Programming required?	2d or 3D?	Available for	Exports to
Construct 2	No	2D (All Genres)	Windows	Desktop, Consoles, Mobile, Web
GameMaker: Studio	No	2D (All Genres)	Windows	Desktop, Consoles, Mobile, Web
Unity	Yes	2D + 3D (All Genres)	Windows, Mac	Desktop, Consoles, Mobile, Web
Unreal Engine	Yes	3D (All Genres)	Windows, Mac	Desktop, Consoles, Mobile
Clickteam Fusion	No	2D (All Genres)	Windows	Desktop, Mobile, Web
Stencyl	No	2D (All Genres)	Windows, Mac, Linux	Desktop, Mobile, Web
Torque 2D/3D	Yes	2D + 3D (All Genres)	Windows	Desktop, Consoles, Mobile
CraftStudio	No	2D + 3D (All Genres)	Windows, Mac, Linux	Desktop

users created a huge forum community with tutorials and questions answered. In addition, it has an asset store where users offer or sell their projects to help other developers.

Other alternatives are Unreal[4] and CryEngine[5]. Both of these alternatives contain state-of-the-art graphics , cross-platform deployments and are well known by popular games in the market developed in its environment [Fra12]. However, they lack a free version unlike Unity, which is also easier to learn [Fra12].

OpenFrameworks[6] and Processing[7] can be more practicable to build prototypes than the cited game engines. They offer a simple library that allows quick project development. Users also create their own libraries and provide them to the tools community. Thus, these technologies have fair support and a large amount of plug-ins provided to developers use in their projects. However, they do not possess game abstractions or graphics capabilities that game engines provide. Therefore, OpenFrameworks and Processing are not ideal to develop a complete digital game.

2.4.2 Nintendo Wii Balance Board Tools

The WBB communicates via bluetooth using Service Discovering Protocol[8] and works as a Human Interface Device. Its data packages has information about the weight and calibration for 0kg, 17kg and 34kg for all four sensors[9]. This data can be used to compute the COP coordinates in the WBB. Some tutorials and libraries exist to ease up WBB integration and use.

Brian Peek in [Pee07] demonstrates how to create a library to manage communications with Wii controllers in C#, which all communicate in similar fashion, including the WBB. The Wi-iLAB library was built on top of this tutorial to give support to MATLAB, a software dedicated to numerical analyses [BSL+09].

Other libraries that support the WBB and are currently being used include:

[4] Unreal, game development framework, https://www.unrealengine.com/
[5] CryEngine, game development framework, http://cryengine.com/
[6] OpenFrameworks, toolkit for creative coding, http://openframeworks.cc/about/
[7] Processing, toolkit for creative coding, https://processing.org/
[8] Bluetooth, wireless communication, https://www.bluetooth.org/en-us/specification/assigned-numbers/service-discovery
[9] WiiBrew, library to communicate with WBB, http://wiibrew.org/wiki/Wii_Balance_Board

- the Wiiboard Simple[10] extends a library for other Wii controllers, Wiimote Simple, to give support for the WBB provided in java and python;
- the WiiC[11] is a library written in C and C++ supports communication for various Wii controllers including the WBB for Linux and Mac;
- the Wii Device Library[12], written in C#, gives cross-platform support to various Wii controllers including the WBB.

These libraries can be used by developers to simplify the WBB integration in a project.

2.5 Summary

Exergames shows promising results when oriented to health-care being capable to create environments for patients to exercise and prevent falls. Likewise, motivating elderly adults to do home exercise oriented to fall-prevention may also be possible through the use of exergames. With the use of the WBB, these exercises may also give important information to therapists, this way capable to supervise and orientate the seniors to improve their balance. This literature research is important for the solution design proposed in the next chapter. The exercise programs provide a set of potential movements to use in elderly fit exergames. Related work provides guidelines for development and demonstrates that digital games have more benefits than purely entertainment to offer. These conclusions give conditions to continue research in order to validate the statements described in subchapter 1.3.

[10] Wiiboard Simple, library to communicate with WBB, https://code.google.com/p/wiiboard-simple/
[11] WiiC, library to communicate with WBB, http://wiic.sourceforge.net/
[12] Wii Device Library, library to communicate with WBB, http://softwarebakery.com/projects/wiidevicelibrary

Chapter 3

Proposed Solution

This chapter describes the proposed solution for this dissertation. The section 3.1 describes the Smartfeet project where the digital exergames developed in this work were integrated and explains its system architecture. The second section describes the WBB data and the possible fall prevention exercises that could be performed with it and consequently used in the developed digital games.

The subchapter 3.3 describes the conceived interactive games to answer this dissertation's scope needs. The idea behind this list was to design multiple possible games to integrate in the final solution. A priority attribute was given to each game in the last subchapter 3.4 in order to identify the most important ones to implement. Prioritization was made in order to organized the available implementation time as developing all the games is not imperative for this dissertation.

3.1 Design and Architecture

Subchapter 1.4 presented the main objectives proposed for this dissertation. They were to develop a fall-prevention oriented exergame application capable of computing automatic balance measures and to evaluate older adults' motivation when using it. In order to reach these objectives, five digital games were designed, two of those being developed. These digital games were integrated in Fraunhofer's SmartFeet project, which is part of their own Exergames framework. This project goal is to address low adherence fall-prevention exercise programes by introducing interacting digital games with motion sensors [SGM+15]. The Exergames framework also integrates other modules for different purposes, like physical rehabilitation. Exergames contains a set of exergames fit to the target populations and uses affordable sensing equipment sensors such as smartphones, Kinect, Leap Motion[1], Orbotix Sphero[2], smartwatches, BITalino[3] and Myo[4] and has support for

[1] Leap Motion, Motion Control hand and finger sensor, https://www.leapmotion.com/
[2] Orbotix Sphero, robotic ball with motion sensors, http://www.gosphero.com/sphero-2-0/
[3] BITalino, toolkit to learn and prototype applications using body signals, http://www.bitalino.com/
[4] Myo, muscle sensor armband, https://www.thalmic.com/myo/

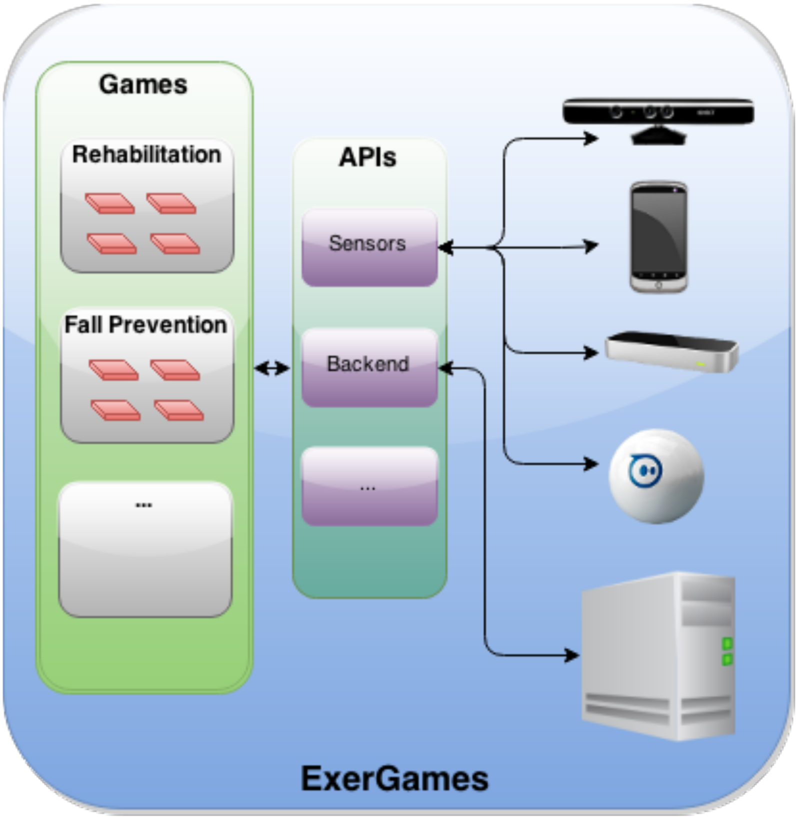


Figure 3.1: Fraunhofer's Exergames architecture in which the solution will be integrated. Figure taken from [SGM+15]

Microsoft Windows, Linux and Android [SGM+15]. The WBB was also integrated in order to take advantage of its features that are proved useful by current literature and to develop digital games that uses it in the scope of this dissertation.

Fraunhofer's Exergames project architecture can be described as a three-tier framework as shown in figure 3.1 [SGM+15]. This architecture design was chosen to be able to be updated with future emerging technologies easily. The architecture can be divided into the following tiers:

- Application Programming Interfaces (API): This component provides the games tier information from the devices each game pretend to use. Any number of sensors can be connected, even sensors of the same type. The sensors availability depends on the backend tier, as communications between them and different operating systems are different.

  - Sensors: Represent the different devices supported by Exergames. They are Microsoft Kinect or similar depth sensing cameras, smartphones, smartwatches, Leap Motion, Orbotix Sphero, BITalino, Myo and WBB. These devices communicate data from their sensors with the API, which gathers information about all the sensors and provides it to the other tier (Games). The WBB was integrated here and the communication with the top layer was implemented to enable its use in the designed games.

  - Backend: Represents the operating system where the application is running. This solution runs on Windows, Linux and Android. However, Kinect is not compatible with the Android version yet. The WBB is also not compatible with Android due to the type of Bluetooth sockets used, which are not supported by recent versions of Android. A Windows application can be used to receive data from all the sensors and send it to Android devices via socket connections. This way, Android devices can receive data from sensors anyway.

- Games: This tier contains all the games already implemented in the project. These games have access to all the available sensors through the API and can use any sensors or combination of sensors, even of the same type. There are two types of games:

  - Rehabilitation: As the original goal was to motivate patients to physical rehabilitation, several games exist for this purpose.
  - Fall-prevention (SmartFeet): More recently, games were added to the project to address the fall-prevention topic. The new games for this solution were implemented here in similar fashion.

This architecture enables adding new devices without changing the whole system. In similar fashion, introducing new games, or changing existing ones, is possible with minimal effort. Therefore, development is much faster and requires minimal adaptation, which is the case of the proposed solution. The project is being developed in Unity to have cross platform support without additional effort [SGM+15]

Figure 3.2 presents the new components added to the Exergames framework. The API receives messages from the WBB and sends them to the new games in the same way it does for other devices in other games. The Balance Assessment module provides functions to compute balance metrics. The new games use the COP to detect different exercises and, based on those and on the game's state, they call functions from the Balance Assessment module to compute the measures only when necessary.

3.2 Nintendo Wii Balance Board

The WBB is developed and commercialized by Nintendo initially as a controller for some WiiFit mini-games. In these games, the WBB tracks the player's COP whose position has to be controlled in order to progress, e. g. Soccer Heading is a game where the player has to move the COP to the left or right to head balls, depending on their trajectory.

The WBB has a circular weight pressure sensor with 2 cm radius in each of its corners. It has a rectangular like shape with 45 cm length and 26.6 cm width. Data from these sensors is sent via bluetooth connections and includes the pressure measured by each sensor and total. This way, COP value can be computed using equation 3.1. Let $i = 1..4$ be an identifier for each sensor (top

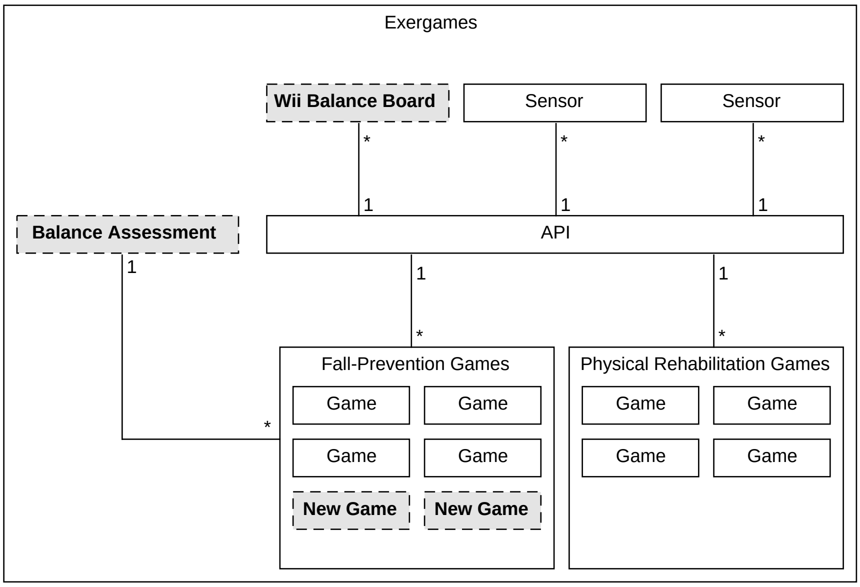


Figure 3.2: Proposed solution architecture.

left, top right, bottom left, bottom right), P_i the position of sensor i and W_i the weight read by sensor i. Then:

$$COP(ML,AP) = \sum_{i=1}^{4} \frac{W_i * P_i(ML,AP)}{\sum_{i=1}^{4} W} \quad (3.1)$$

Manipulating the position of each sensor in the equation according to a rotation from the WBB original position will give a correct COP in ML and AL components. For instance, if the WBB is rotated 90^o, the top left sensor would actually be the WBB top right and its position would be (-24.5, 43) instead of (43, 24.5). This way, the WBB usage is not stuck to one position.

Tracking the user's COP, several movements or exercises can be detected or measured. Balance scales and exercise programs cited in Literature Review, subchapters 2.1.1 and 2.1.2, were analyzed in order to identify what movement could be detected with the WBB and included in fall-prevention oriented exergames. The following list presents the analysis conclusion.

- Calf raises

  To perform a calf raise, one has to stand with the feet shoulder-width apart. Then, raise the heels and stand only with the toes. Finally, lower the heels to the initial position. This exercise can be read by the WBB as the COP's position moves forward and the top sensors sustain almost all the person's height. Calf raises are present in OTAGO [CR03], FAME [EDP06] and Growing Stronger [SEB+02] exercise programs to promote leg, ankles and calves strength and balance. A calf raise movement is demonstrated on the left of figure 3.3.

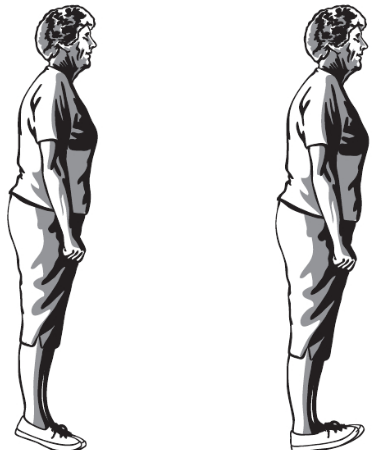


Figure 3.3: Calve (left) and toe raises (right) demonstration [CR03].

- Toe raises

  Toe raises are similar to calf raises, but the goal is to raise the toe and stand on the calves. This exercise can be read by the WBB as the COP's position moves backwards and the bottom sensors sustain must of the person's weight. Toe raises are present in OTAGO [CR03] and FAME [EDP06] exercise programs to extend calf raises benefits. A toe raise exercise is demonstrated on the right of figure 3.3.

- Knee bends

  To perform a knee bend, one has to stand with the feet hip-width apart. Then, slowly bend the knees to a comfortable position. Finally, slowly return to the initial position. The knees must be facing forward and the back must be straight all the times. While performing a knee bend, COP's position moves backwards and it can be detected by the WBB. This movement is used in some WiiFit games. Knee bends are part of Otago exercise program [CR03] to

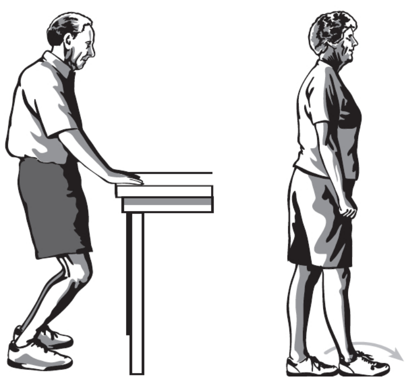


Figure 3.4: Knee bends (left) and heel toe standing (right) demonstration [CR03].

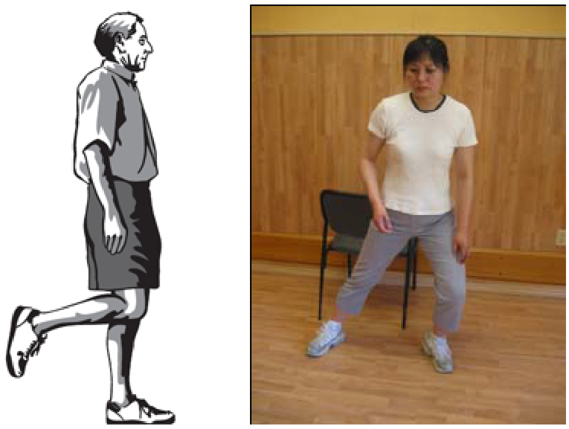


Figure 3.5: One leg standing [CR03] (left) and weight shifts [EDP06] (right) demonstration.

promote balance and leg muscle strength. A knee bend movement is demonstrated on the left of figure 3.4.

- Heel toe standing

  Heel toe standing, or tandem stance, is holding a standing position with the feet facing forward and one foot's toe touching the other's heel. This exercise can be detected by the WBB, if rotated 90º, as the weight must be distributed similarly in both top and bottom of the WBB. Heel toe standing is present in OTAGO [CR03] and FAME [EDP06] exercise programs to promote balance but is also used in the BBS [BWDWG89] as a measure of balance itself. The tandem stance can be seen on the right of figure 3.4.

- One leg stand

  This exercise consists in holding a standing position with only one foot as seen on the left side of figure 3.5. Naturally, this stance moves the COP's to the foot on the floor and the person weight to the side where the same foot is placed which can be read by the WBB. One leg stand traing is recommended by OTAGO [CR03], FAME [EDP06] and Melo's [Mel08] exercise programs to promote balance, leg strength and one leg steadiness which is used in daily activities such as dressing and climbing stairs. One leg stance is also used in BBS [BWDWG89] and FAB [RLW06] to measure balance.

- Weight shifts

  To perform a weight shift, one must stand with the feet about one and a half shoulder width apart. Then, bend one knee to shift the weight to that side as demonstrated on the right of figure 3.5. Finally, go back to the original position. By shifting, the COP's also moves to the same side as the weight, thus, the exercise can be detected with the WBB. This exercise is used in some WiiFit mini-games. Weight shifts are part of FAME [EDP06] exercise program to promote balance and leg strength and are present in BBA [Tys04] to measure balance.

Figure 3.6: Forward reach (left) and stepping (right) demonstration [EDP06].

- Forward reach

  Forward reaching implies standing with the feet shoulder width apart, raising one or both arms to the shoulder's height and lean forward as far as possible as seen on the left of figure 3.6. This movement also moves the COP forward being detectable by using the WBB. Forward reach is used in FAME [EDP06] and Melo's [Mel08] exercise programs to promote balance and forward stability. This exercise is also present in BBS [BWDWG89], BBA [Tys04] and FBA [RLW06] making it essential to measure balance.

- Stepping in various directions

  Stepping is a fundamental daily activity and is used as a warm up or main exercise. FAME [EDP06] and Melo's [Mel08] exercise programs use stepping forward and backwards and also sideways to promote balance, leg strength and gait speed improvement to react better to balance loss. Stepping is also used in BBS [BWDWG89] and BBA [Tys04] with a stool to assess balance. Using the WBB, it is possible to detect if users step with a foot on one side of the board, stand with both feet, or leave a foot or both from it. This detection is also present on some WiiFit mini-games. On the right side of figure 3.6 is demonstrated a step to a stool.

- Sit to stand

  To sit and to stand up are two of the most used exercises in daily activities but they are also demanding movements. This exercise can be seen in figure 3.7. While sited, a person exerts less pressure on the floor with their feet than when standing up. This way, the WBB can be use to detect this transition. Sit to stand training is used in OTAGO [CR03], FAME [EDP06] and Melo's [Mel08] exercise programs to promote lower limb strength and balance and is also used in BBS to assess balance.

- Stand unsupported

  Standing may be challenging for balance impaired people. The number of seconds a patient can maintain a standing position is used to assess balance in BBS [BWDWG89] and BBA

Figure 3.7: Sit to stand demonstration [EDP06].

[Tys04]. COP analysis during standing position is the main form of balance quantitative analysis [DF10]. This assessment is made with highly advanced and expensive force plate, however, with the promising results of Clark et al. [CBP+10] this assessment could also be done with the WBB. While it may not be a interaction movement for a exergame or a exercise that the WBB can detect, forced pauses can be included during gameplay to make the player stand and assess its balance while standing. Naturally, a person standing can be seen on figure 3.7 after performing a sit to stand movement.

Several movements from fall-prevention exercise programs and balance assessment scales possible to detect using a WBB are here identified. These exercises could be used to interact in fall-prevention oriented exergames. The next subchapter present the suggested game ideas for this dissertation's system that include one or more of the exercises described above.

3.3 Game Proposals

This subchapter presents the preliminary exergames design to implement. Each section here describes the proposed games and the exercises as well as justifications for the choices made and the measures that can be taken from the devices. The exercises required to play the games were chosen accordingly to their benefits towards fall-prevention and the possible evaluation metrics that sensors can provide. The use of the WBB is mandatory in this dissertation's scope, but other sensors can be used at the same time.

3.3.1 Hungry Cat

This game is oriented to calf and toe raise movements while using the WBB to detect the movements. Calf and toe raises strengthen calves and ankles and improves stability and balance. In the game, the player has to avoid stumbling in the cats while they try to rub in the player's legs.

[5] Cat image taken from: https://www.iconfinder.com/longshadowicons
Pot and shoes icons taken from: https://www.iconfinder.com/longshadowicons

Figure 3.8: Hungry Cat sketch[5]. The player has to raise his toes or stand on them to avoid the cat.

- Description: The player is cooking in a kitchen and bringing food to the table. The house cats are also in the kitchen and they are hungry as well. They try to rub themselves in the player's legs, who loses balance and may fall. This game's objective is to avoid the cats movement using calf and toe raises during a certain amount of time. A sketch of this game can be seen in figure 3.8

- Exercise: In order to perform a calf or toe raise, the user must stand with their feet shoulder-width apart. When a calf raise is pretended, the user slowly comes up onto the toes and holds for two to four seconds. In toe raise case, the player raises the feet front part instead. After the interval passed, slowly lowers raised feet part back to the ground. The player can use a chair to keep balance or can play standing.

- Progress: This game has several difficulty levels. Lower levels require fewer movements, held by minimum time interval (two seconds), with longer interval between raises and distinct calf raises phase and toe raises phase. Higher levels increase the number of repetitions, raising the minimum time interval (four seconds) and alternate between calf raise and toe raise with smaller interval between the movements.

- Benefits: This exercise promotes both leg strength and balance. Calf raises strengthen calves and ankles and restores stability and balance [SEB+02]. Consequently, these exercises should be included to decrease fall risk. They are used in Otago [CR03], FAME [EDP06] and Growing Stronger [SEB+02].

- Evaluation: The WBB can measure if the user is doing calf or toe raises and if the feet are properly placed, i. e. when the player does a calf raise or a toe raise, the bottom or top pressure sensors, respectively, do not have any pressure. Therefore, it is possible to read the number of calf and toe raises done by the user and the movement's duration.

  Using this metrics, users can be evaluated by the number of successful and unsuccessful exercise attempts and how much time the raise position was hold.

The WBB provides a reliable way of detecting calf and toe raises. Therefore, it can be used to create an interactive game that uses it to make this exercise funnier with the same benefits.

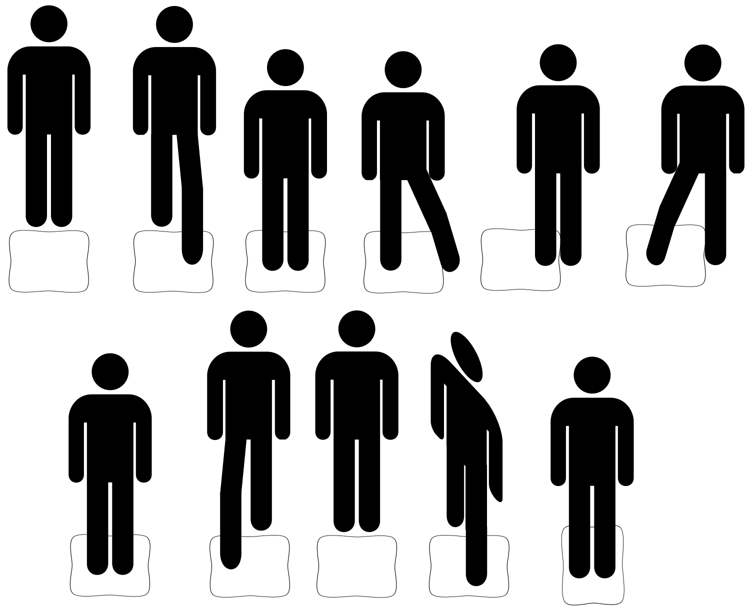


Figure 3.9: Step Dance sketch. The player has to perform a step sequence. All frames are seen from the game set up point of view except the last one which is viewed from the left.

3.3.2 Step Dance

This game explores thoroughly the stepping exercise. Steps are easily read by a smartphone, however, the WBB can introduce several new ways of stepping such as stepping sideways and rotating during the exercise. Figure 3.9 shows a sketch of a player playing the game.

- Description: The player is preparing for a dance contest. The allowed moves are stepping forward, backward or sideways and varying their orientation between left, front and right. The objective is to memorize the instructor's movements and repeat them. Movements should be done according to a music's rhythm.

  Multiplayer can be introduced in this game. Several users should follow the same instructor or one of the users can play the role of the instructor for the others to follow.

- Exercise: The user starts the game standing behind the WBB and waits for the instructors movements. These movements consist in stepping in different directions, either place left or right foot on the WBB, place left or right foot outside the WBB in front, behind, on the left or on the right of it. Successive movements must alternate between feet and be similar. For instance, when both feet are outside the board, step right foot on the board must be followed with step left foot on the board. Another example, with both feet on the board, step left foot on the left of the board should be followed with step right foot on the left side of the board.

- Progress: This game can be divided in two tasks. First is memorizing movements and second is their performance. Game difficulty is increased by adding more movements to memorize and reducing the time between them, changing the background music to one with more rhythm.

- Benefits: Stepping preserves stability and its performance is related to balance improvement [Mel08]. Doing steps in all directions trains leg muscle activation and body reaction to loss of balance [Mel08]. Therefore, training these movements can prevent falls. Stepping in multiple directions is included in FAME [EDP06] and in Melo's program [Mel08]. Stepping on a stool or similar is part of the BBS [BWDWG89] and BBA [Tys04].

  In addition to the exercise, this game includes a cognitive challenge, as the player needs to memorize the sequence before starting to step. As stated in the introduction, chapter 1, cognitive problems can lead to falls and some studies suggest that cognitive therapy may prevent falls mainly when the patient is asked to perform two tasks at the same time [SJHYS+11]. Memorizing and stepping is an example of dual task training that may contribute to fall prevention.

- Evaluation: Several sensors can be used in this game. The WBB can work as a small step, forcing the user to step up and down. It also can measure if a foot is placed on the left, on the right of the board and, in case a rotation is asked, on the top and on the bottom as well. As stated above, smartphones can be used to check if the user is properly stepping. Lastly, the Kinect can trace the user's position to confirm that forward, backward and side movements are done correctly.

  Evaluation measures taken from the sensors data are the number of success and error hits, the number of steps done and the velocity of them. Errors have two types that can be determined. The first is movement error that happens when the user makes a movement that it is not supposed to be done. The second is lack of a movement that happens when the user cannot keep up with the music rhythm.

Stepping is important to prevent falls when a loss of balance occurs. Training steps forward, backward and sideways prepares legs to answer losses from every direction. This game presents an interactive way to step and offers a multiplayer mode to increase motivation. The sensors used in this game can give important measures as stepping is present in balance assessment scales.

3.3.3 Segway Stroll

In this game, the player has to drive a Segway[6]. To interact, the user has to stand in the WBB and perform forward reaching or weight shifts. These movements can be read by the WBB alone, however, other sensors can be added in order to force the user to do them correctly. Other movements can be included by introducing obstacles in the levels. Figure 3.10 is a sketch of the idea for this game.

[6]http://www.segway.com

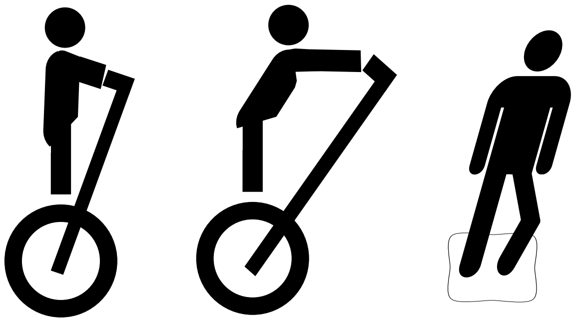


Figure 3.10: Segway Stroll sketch[7]. The player has to perform a forward reaching to accelerate and weight shifts to turn. The first two frames are in-game sketch while the last represents the player.

- Description: The player is leaving home to try out the newly bought Segway and takes a stroll in the town. The Segway offers full control, the user has to forward reach in order to move, stand to stop and perform weight shift to turn. In higher levels, objects can be introduced to add more exercises to the game. The objective is to follow a path and return home.

- Exercise: To perform a forward reach, the player must stand with feet shoulder-width apart. Then, raise one arm to the shoulder and lean forward as far as possible. Finally, the player returns to the initial position. Both arms should be used alternately.

  The initial position for forward reaching and weight shifts is the same. To perform a weight shift, bends one of the legs placing more weight over that leg. Weight shifts should be done for each leg alternately.

- Progress: First levels have small paths and require less movements with less duration to complete. Higher levels have more complex paths with more demanding exercises.

- Benefits: These game's movements help seniors to train balance control when their center of gravity changes [Mel08]. Forward reaching improves the limits of forward stability [Mel08]. Weight shifts are present in FAME [EDP06] and BBA [Tys04], forward reaching is present in FAME, Melo's program [Mel08], BBA and BBS [BWDWG89] and standing is part of BBS and BBA and provides quantitative data for balance assessment [CBP+10].

- Evaluation: Sensors used to read the player's movements provides useful data for analysis. The WBB can track changes to the user's centre of pressure in all movements. Kinect can be used to force the player to do the movements correctly, in terms of body pose. Smartphones or smartwatches can also be used when forward reaching in the player's hand or wrist.

  Evaluation measures taken from this exercise are the number of repetitions and duration of each movement, the amplitude of forward reaching and weight shifts and the COP while the

[7] Segway and driver based on icon from: http://www.google.com/design/

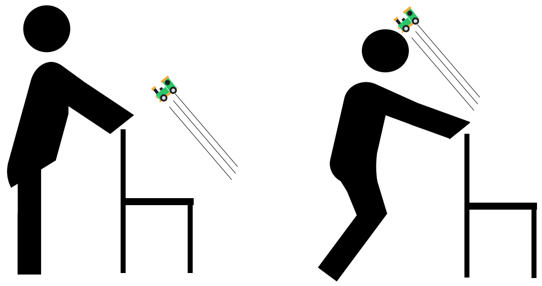


Figure 3.11: Grumpy Grandson sketch[8]. The player has to perform knee bends to avoid getting hit in the head.

player is standing which can be used to compute other metrics useful for balance assessment, e. g. COP path and COP velocity [CBP+10].

This game presents an interactive way to assess balance, as the movements tracked are part of several measures. While useful for assessment, these exercises also promote balance when done regularly and consequently, decrease fall risk.

3.3.4 Grumpy Grandson

Knee bends can be read by the WBB and are required in this game in order to avoid getting hit with objects. Other sensor can be added to the gameplay to obtain better evaluation metrics. The idea for this proposal can be seen in figure 3.11

- Description: The player is at home happily taking care of the grandson. However, the grandson got angry with something and decided to throw all of his toys towards the player's head. Unfortunately, he has incredible aim, therefore the player has to perform knee bends to avoid being hit by a flying toy.

- Exercise: In order to perform a knee bend, the player must stand with the knees hip-width apart. Then, slowly bend the knees as far as comfortable, keeping them facing forwards and keeping the back straight at all the times. Finally, slowly return to the initial position. The player can use a chair for stability.

- Progress: In higher levels, the grandson has more toys available and is quicker to react when the player returns to the standing position.

- Benefits: Knee bends are used in the Otago program [CR03] for balance and strength promotion. As poor balance and leg strength are fall risk factors, frequent practice of this exercise may decrease falls in the elderly.

[8]Man figure based on icon from: http://www.google.com/design
Toy from: https://www.iconfinder.com/Badger

Figure 3.12: Scooter chase sketch[9]. The player has to stand with a foot in front of the other to keep balance.

- Evaluation: The WBB can detect knee bends by the changes in the user's COP. Adding a Kinect can be useful to guarantee that the player does the exercise correctly. A Kinect or a smartphone in the player's pocket may be useful to measure the movement's amplitude.

  This way, the evaluation measures that can be taken from the sensor's data are exercise repetition, duration and amplitude. The player's strength and balance evolution over time can be assessed with this data.

This game provides and interactive way for elderly adults to perform knee bends, which can promote balance and leg strength, decreasing fall risk.

3.3.5 Scooter Chase

In this game, the player has to tandem stand, i. e. stand with a foot in front of the other, in order to balance while riding a scooter. The movement performance is read by the WBB and transmitted to the game. Figure 3.12 is a sketch for this proposal.

- Description: The player notices something is missing, the cat ran away. The player follows the cat, but it is too fast. The player sees the grandson's scooter, gets on it and accelerates to catch the cat. Tandem standing is needed to keep balance and avoid falling from the scooter. The main goal of this game is to catch the cat and return without falling.

- Exercise: In order to perform a tandem standing, the player must place on foot directly in front of the other and hold for some seconds. For the movement to be read by the WBB, the player should turn it 90^{o} and place one foot on the bottom side and the other in the top side of the board.

- Progress: In higher levels, the scooter's sensitivity to COP changes and the time needed for the player to stand in a tandem position increases.

[9]Scooter and driver based on icon from: http://www.google.com/design/

- Benefits: Heel to toe standing is indicated in Otago [CR03] and FAME [EDP06] programs to promote older adults' balance. In addition, tandem standing is also used as a balance measure in the BBS [BWDWG89].
- Evaluation: The WBB provides information about the tandem standing. These readings can be used to determine the number of repetitions and the duration of each standing. COP path and sway in this exercise may be useful to assess balance as well.

Tandem standing promotes balance and consequently, decreases fall risk. At the same time, it can also be used to assess balance.

3.4 Development Priority

The games proposals in the last chapter were analysed in order to identify the most important ones and assign priorities to their development.

Several factors were taken into consideration in this analysis. Firstly are the possible outcomes as games with more benefits or more important evaluation metrics are more justifiable to implement. Secondly is the nonexistence of the same or similar exercises in the SmartFeet project where this solution is integrated, as exploring other exercises than those already present is desirable. Third factor is the proposal's originality and interactivity. These metrics promote enjoyment and motivation as they give new experiences to players. Last factor is the required endeavor for the implementation as time and resources were limited and more prototypes are better than a single game.

The following list presents the analysis' conclusion, sorting the proposals from the one with higher priority to one with lower:

1. Scooter Chase: The interaction present in this game is the most exemplary of how the WBB capabilities can benefit fall-prevention exergames. It was expected to use exclusively the WBB to interact without need for other sensors to be present, although smartphone communication was added to this game to improve the gameplay. All changes are described in the Implementation chapter, 4. Tandem standing used in this game is important both to promote and measure balance and was not present in SmartFeet at the time of the proposals analysis. This way, this game was considered the most important to implement.
2. Segway Stroll: This proposal and Scooter Chase have similar characteristics. However, this one presents a more complex interaction with at least three movements and the addition of other sensors to force the player to do the correct movements. Nevertheless, there are several evaluation metrics obtainable during gameplay, thus this proposal has received high priority as well. Forward reaching is not present in the SmartFeet project neither a way for measuring COP while the user is standing.
3. Grumpy Grandson: This proposal was given medium priority. The game can be played with the WBB alone, but other sensors may be useful for better data collection. Performing knee

bends can promote balance and leg strength, then this game can be an interactive way to prevent falls. This exercise is not present in SmartFeet at the time of the proposal.

4. Step Dance: Step based games already exist in Smartfeet. This game adds multidirectional and sideways steps, but the exercise is still similar to standing stepping. In addition, this proposal lacks originality as there are many similar games in the market. These reasons gave this proposal lower priority.

5. Hungry Cat: Although the present exercises are important, this proposal was attributed with the lowest priority due to being difficult to be played by users and requiring more effort to implement than the other proposals. This idea was considered the hardest one to turn into a game.

This concluded the solution idealization step. After this phase, the games' implementation was started beginning with the one with the highest priority.

3.4.1 Summary

A balance assessment framework and five different games are proposed focused in the WBB features. The games use exercises from fall-prevention exercise programs. The WBB can be used for both movement detection and COP based balance assessment during the gameplay. The solution is integrated in the Exergames framework, which already has support for several devices that can be used together with the WBB.

Chapter 4

Implementation

This chapter documents the dissertation's development phase. From the five game proposals listed in last chapter's subchapter 3.3, Game Proposals, two games were implemented, which are the most important ones accordingly to the prioritization process described on subchapter 3.4 of the same chapter: Scooter Chase and Segway Stroll.

The first subchapters describes the balance measures that the system is capable to compute. Then, each game has a subchapter where is described their basic gameplay and respective interaction, main goals, heads up display (HUD) and evaluation metrics taken. Different approaches that were taken in consideration are also documented as well as the reasons for the final version.

4.1 Balance Measures

One goal for this dissertation was to provide physiotherapists or care-takers a mean to monitor a senior's balance evolution. Equation 3.1 allows COP computation with data from the WBB. However COP alone is not useful for balance assessment [DF10]. Duarte and Freitas [DF10] indicated that the best COP related metrics for balance assessment were COP's mean velocity, total oscillation, path chart and displacement (amplitude) over time. This chapter presents how this metrics are calculated in the system.

Before the metrics stated in last paragraph were implemented, statistical measures were included in the system. They were average, variance and standard deviation. Average is used to determine an initial position COP before playing and to compute the COP's mean velocity. Variance and standard deviation were implemented to determine if the player's COP would move more or less, indicating the balance stability was worse or better, respectively. These metrics are calculated in run-time to avoid recording unnecessary data in disk space and perform heavy operations when the game finishes. In order to enable this, the average is computed with the cumulative moving average (CMA) equation:

$$CMA_n(CMA_{n-1}, x_n) = \frac{(n-1)CMA_{n-1} + x_n}{n} \tag{4.1}$$

Where x_n is the new value to enter the average, n is the number of values and CMA_0 = 0. To compute the variance, a computing shifted data equation is used. First, this method takes advantage of a variance property: Var(X - k) = Var(X), where k is called the invariant and can be any number. The developed method uses the first value as k. Next, the variance is computed using these equations:

$$Eq_1 = \sum_{i=1}^{n} x_i - k \tag{4.2}$$

$$Eq_2 = \sum_{i=1}^{n} (x_i - k)^2 \tag{4.3}$$

$$s^2 = \frac{Eq_2 - \frac{Eq_1^2}{n}}{n-1} \tag{4.4}$$

Equations 4.2 and 4.3 are computed in run-time as adding or even removing values is possible. Variance is obtained with equation 4.4 when the game or exercise finishes. With the variance value, the standard deviation is computed applying a square root:

$$\sigma = \sqrt{s^2} \tag{4.5}$$

COP's mean velocity and total oscillation are computed in run-time as well. The COP's mean velocity can be calculated as a CMA and the COP's total oscillation is a sum. The equations used are based on Duarte and Freitas [DF10] function definitions for MATLAB:

$$v_n = \frac{|COP_n(ML,AP) - COP_{n-1}(ML,AP)|}{\delta t} \tag{4.6}$$

$$\bar{v_n} = CMA_n(v_{n-1}, v_n) \tag{4.7}$$

$$\bar{v_t} = ||v_n|| \tag{4.8}$$

$$to = \sum_{i=1}^{n} ||COP_i - COP_{i-1}|| \tag{4.9}$$

In equation 4.6 the instant velocity is calculated in ML and AP directions. The equation 4.7 computes the mean velocity since t_0 until t_n also in ML and AP direction, being t_i the time when v_i takes place. The equation 4.8 computes the total mean velocity.

To draw the COP's path and displacement, COP and respective timestamp is written in a file. This file can be parsed by an application developed for this purpose which generates a Microsoft Excel file and automatically draws the COP's path and amplitude chart and in addition a frequency

Figure 4.1: A senior playing Scooter Chase.

map of times the COP was tracked in a certain area. These areas have 1 cm^2 area and a COP of (3.4,4.5) would be counted at the area (3,5).

4.2 Scooter Chase

Scooter chase is a casual game where the player rides a a scooter with the goal of catching a cat. The system uses a WBB, rotated 90^o from its normal position, to simulate a scooter's base and a smartphone to simulate the handlebar. This game can be used to promote balance improvements and to assess it as well. A senior playing this game can be seen in figure 4.1. The sections under this subchapter give more details of the game and its development.

4.2.1 Goal

The Scooter Chase main goal is to catch the cat. However, it is not enough to catch it one time, as it runs away again several times. The player has a 150 seconds time limit for reaching the cat on ten occasions.

To achieve a better result, the player should avoid obstacles in the scenario such as cars and streetlights. Balance performance is also considered when computing the final result to motivate the player to remain tandem standing longer and tremble less.

4.2.2 Basic Gameplay and Controls

There are two interactions possible in Scooter Chase: to move and to turn.

The main development goal was to use tandem standing exercise as an interaction to move the player. An algorithm was written to detect when the player is doing the exercise and when it does, the game character moves at constant speed and when the player leaves the position it stops.

Figure 4.2: Heel toe standing on top of the WBB required to play Scooter Chase.

Stopping can also be used to figure what to do next. A player performing the tandem stance in order to play this game can be seen in figure 4.2.

Possibility to turn was added to make the game more dynamic and attractive, enabling the cat to make curvilinear trajectories and obstacles in the path which the cat can jump. The first approach to this interaction was to use COP's sway in the medial-lateral direction using arms wide open rotations to cause it. However, this was a poor decision as it was observed that arm rotation barely affected COP coordinates and the human body tends to compensate these movements with the feet causing the COP's to actually move in the not pretended direction in most cases. Finally, smartphone interaction was added to surpass those difficulties, using changes in its three dimensional orientation to rotate the character. Adding a second device was more effective than using the WBB to turn while tandem standing.

4.2.3 Game Flow

This game has four difficulty levels where the path the cat runs is different and has more obstacles to the player. The cat and scooter's speed and handlebar's sensibility increase in higher levels. The first level has a small tutorial to explain the players the mechanics and the logic. Figure 4.3 is a state diagram that describes the game flow.

In the tutorial, instructions are given to the player to explain the calibration process and how to play. These instructions are displayed as seen if figure 4.4. First, the player must apply pressure in WBB rear-side for the system to recognize its orientation. Then, the player must hold the smartphone to calibrate it, which consists in getting the device reference orientation. Finally, the game controls and goals are explained to the player: how to move, how to turn, follow an arrow (that points to the cat) and catch the cat.

After reaching the cat for the first time, normal gameplay will take place as an ordinary level. The cat will run and stop in another position where the player can catch it again. This process

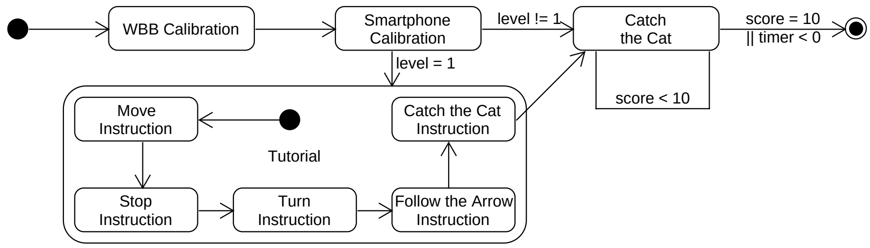


Figure 4.3: Scooter Chase game flow.

repeats three times. The next point can be directly in front, in front but to the left or right or even backwards. While running, the cat may jump over cars whereas the player must go sidewards. When the player catches the cat for the tenth time or the time limit is surpassed, the game ends and a score is given and displayed to the player as seen in figure 4.5. This score takes into account the number of times the cat was caught. The score screen's also shows the number of times the player hit an obstacle, the total time standing in the tandem stance and the balance performance according to the Tandem Stance Test [HBP+12] described in the exercise analysis.

Initially, the tutorial section was much simpler. Game control instructions would first appear in the screen and disappear after a few seconds. Then, the calibration would take place and after it the game would start. The tutorial section was added as it was observed during the first test phase, detailed in subchapter 5.1, seniors would not read the first instructions and when the game started they did not know how to play and after an explanation, they would not understand the game goals.

4.2.4 Game Interface

Scooter chase run in a city environment, divided in several streets. The city has several objects, such as cars and boxes, which the player has to contour while the cat jumps over.

Figure 4.4: Tutorial message in Scooter Chase.

Figure 4.5: Scooter Chase score screen.

Scooter Chase displays several information to the player in order to help him. During gameplay, the player can see the total number of stops the cat does during the level as well as the number of times it was already caught in the top of the screen. A clock is also present to indicate the remaining time the player has to finish the game at the top right corner. An arrow will appear above the character if the cat is far way to help the player locate it. A game's screenshot can be seen in figure 4.6.

As stated above, tutorial messages will appear to the player in the beginning of the game, either to instruct the player to calibrate the devices or to explain the game's logic and mechanics as seen in figure 4.4. The score screen, seen at the end of the game, presents scores to the user, which are the number of times the cat was caught, the number of times the player hit an obstacle, the total time standing in the tandem stance and TST result, as seen in figure 4.5.

Figure 4.6: Scooter Chase screenshot.

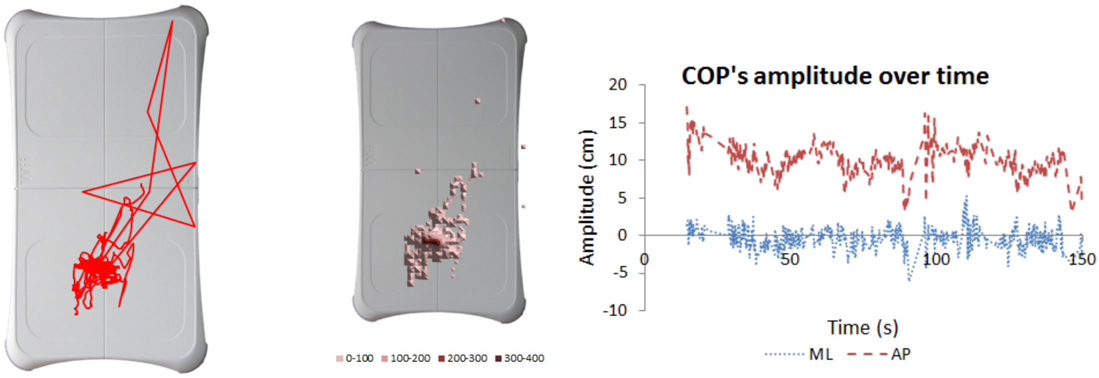


Figure 4.7: COP's path chart on the left, COP's frequency map on the center and COP's amplitude over time, all taken while performing a tandem stance in Scooter Chase

4.2.5 Exercise Analysis

As stated in the Game Flow section, 4.2.3, the first balance assessment metric present in this game is the Tandem Stance Test (TST) [HBP+12]. This test is clearly appropriate to use in this game as it takes into consideration the maximum time a patient can maintain a heel toe standing pose. The result from this test can be low, maximum time between 0 and 9 s, medium if between 10 s and 29 s, or high otherwise. The terminology was changed to weak, fair and good to inform the players better about the assessment. A classification of excellent was added if the player can maintain the pose through all the game.

In addition, the COP's mean velocity and total oscillation are computed and recorded in a file. This file also contains the COP tracking needed to generate the COP's path, amplitude over time and frequency map. On figure 4.7 is presented on the left an example of a COP's path chart, on the center a COP's frequency map and on the right is a COP's amplitude over time chart, all taken from one participant's tryout in Test Phase 2, described on subchapter 5.2. These metrics could be useful for a balance assessment from a physiotherapist. This way, it would be practicable to regularly evaluate patients by distance through the use of exergames.

4.2.6 Game architecture

The architecture for this game, described in figure 4.8, is layer based as influenced by the Exergames architecture, described in subchapter 3.1. The WBB and smartphone are integrated in Exergames API, thus they can be used to interact with the games. Two listeners were developed to receive and parse the messengers. The WBB Listener receives a message with the pressure on each WBB sensor and the total pressure; with these data, it computes the COP.

The Tandem detector determines if the player is performing a tandem stance by examine it the COP, provided by WBB Listener, is between certain limits. The Sensor Fusion takes the current smartphone orientation, using the accelerometer and the gyroscope, with the calibrated device reference orientation, resulting in the angle the player turns.

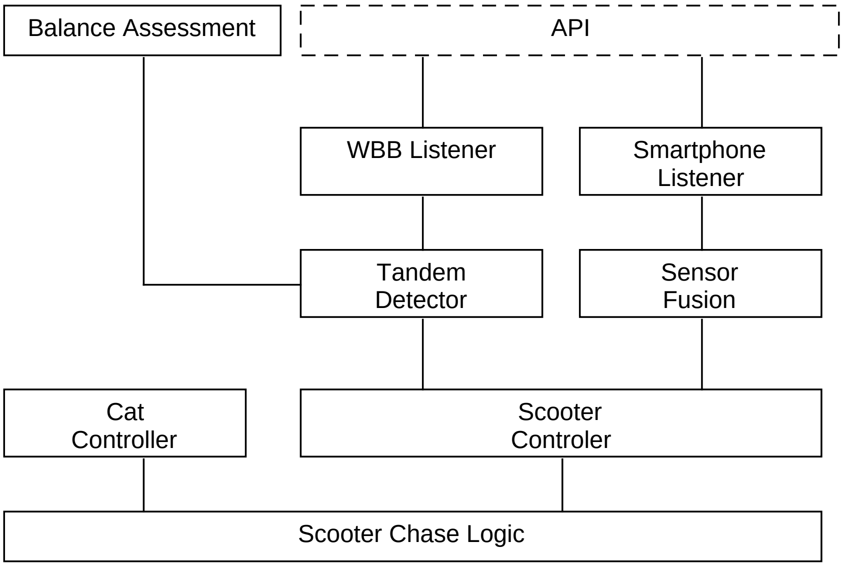


Figure 4.8: Scooter Chase Architecture.

Balance Assessment provides functions for the system to assess balance. It does not receive the COP directly by the API as it does not know when to start the computation. This task was then attributed to the detection algorithm, which needs the COP anyway.

The Scooter Controller sees the results on both detectors and determines how to move. The Cat's Controller receives a point to where the cat must go. When it reaches that point, the cat will stop until the player catches it. Then, it will run away again. At the tenth successful catching, the game ends.

4.3 Segway Stroll

Segway Stroll places the player traveling in the city with a Segway. The main goal is to follow a path given by the system. Unlike the first game, this one only requires the WBB to be played and two different exercises are used to fully control the character. Nonetheless, a chair is recommended to be present as a balance support because some of these exercises can be dangerous for beginners. A senior playing this game can be seen in figure 4.9.

4.3.1 Goal

A level is composed with ten checkpoints. A checkpoint is a set of two flags placed in the road where the player shall pass between them in order to earn points. If the player surpasses a checkpoint without passing between the flags, it will disappear and a second chance to earn points in it is not given. Similar to Scooter Chase, a time limit of 150 seconds exists for the game to be completed. There are obstacles in the road, which the player must avoid such as crates or cars. In

Figure 4.9: Senior performing a forward reach movement while playing Segway Stroll.

addition, there are traps where the player must stop the segway for some time in order to progress, e. g. a traffic light turns red.

4.3.2 Basic Gameplay and Controls

To play Segway Stroll, the player must use two different exercises while on top of the WBB.

To accelerate, the user shall perform a forward reaching exercise. Forward reaching is detected by the game using the readings from the WBB. The segway will accelerate faster if the COP moves more forward in the AP axis, motivating the player to increasing the amplitude of this exercise. A chair is recommended to be used as support to avoid the player falling forward. The senior playing this game on figure 4.9 is performing this exercise to accelerate the segway.

The second interaction is turning the segway. This can be made by pressing more the WBB to the desired side while forward reaching. This mechanic was implemented to add more interactivity to the game. Consequently, the WBB sensitivity to turn is very high in order to make this interaction effortless. Initially, the idea was to perform forward reaching and weight shifting exercises sequentially where the weight shifts were performed in order to turn. These mechanics were changed as it did not promote holding the stances or making several repetitions. Then, it was decided to make a game in a straight line with obstacles rather than a game in which the player must make bigger turns.

Lastly, to brake the segway, the player must perform a toe raise. This exercise was added as it is used in fall-prevention exercise programs and it improves the game mechanic. The segway will lose velocity gradually when not accelerating, but braking was added to provide sudden stops which are important to avoid traps. Once again, a support should be present in order to avoid the player falling backward as the WBB front may rise when the player performs a toe raise. This exercise can be seen on figure 4.10.

Figure 4.10: Senior performing a toe raise movement on the WBB required to play Segway Stroll.

4.3.3 Game Flow

Similar to Scooter Chase, this game starts with the calibration phase and a small tutorial that explains the player how to control the character and what is the main main goal. There is just one difficulty level and the tutorial is always present. After the tutorial, the player has to complete the game level. Figure 4.11 describes the game flow in the form of a state machine.

To calibrate the WBB, the player must exert pressure on the balance's right side. Then, the user must stand on the WBB in order to compute a mean COP. This is used to measure the exercises amplitude and respective effects in the game.

In the tutorial, the player is first asked to accelerate and then to reach the first checkpoint. Secondly, the system explains the user how to brake. At this time, the player is forced to stop at a crossing and let a car pass, experiencing the brake mechanism. After surpassing this trap and reaching the following checkpoint, the game explains the player how to turn. Similarly to the last step, a set of crates appears in the road to force the player to turn. When the player reaches the next checkpoint, the tutorial ends and the game progresses without more instructions. Tutorial and calibration instructions are displayed as seen in figure 4.12

The game logic is the same applied during the tutorial but without instructions. The game has more obstacles, traps and checkpoints with or without time. In the end, a final score is presented

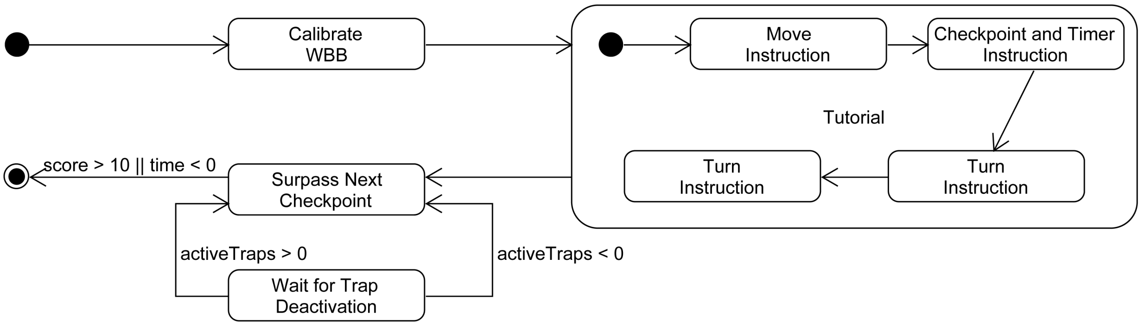


Figure 4.11: Segway Stroll game flow.

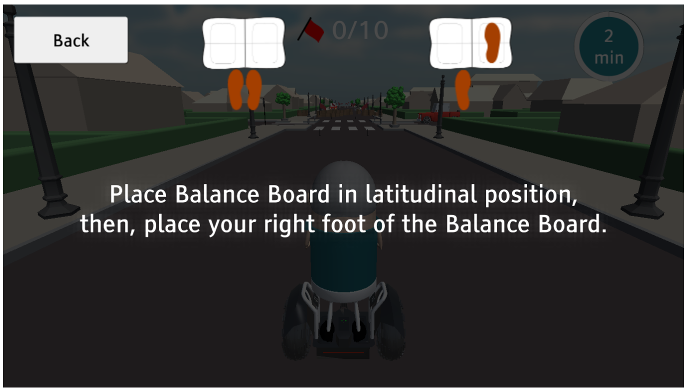


Figure 4.12: Segway Stroll tutorial message.

based on the number of checkpoints successfully reached.

4.3.4 Game Interface

Segway Stroll's interface is very similar to the Scooter Chase's one, described in section 4.2.4. The game is placed in the same city with the same elements, except for the cars and crates that are present in different positions. In addition, cars can move in this game. Sets of flags, called checkpoints, are present in the streets. This game's main goal is to pass between the flags of each checkpoint. If the player has a time limit to surpass the next checkpoint, the remaining number of seconds will appear in the screen. Instead of showing the number of times the player caught the cat, the number of checkpoints successfully surpassed and the total of checkpoints are displayed on the top of the screen. Lastly, traffic lights are present as well as another obstacle to the player. The game interface can be seen in figure 4.13

Calibration and instruction messages are shown to the player in the same way as of Scooter Chase. A message display can be seen in figure 4.12. The methodology is also used to warn the

Figure 4.13: Segway Stroll screenshot.

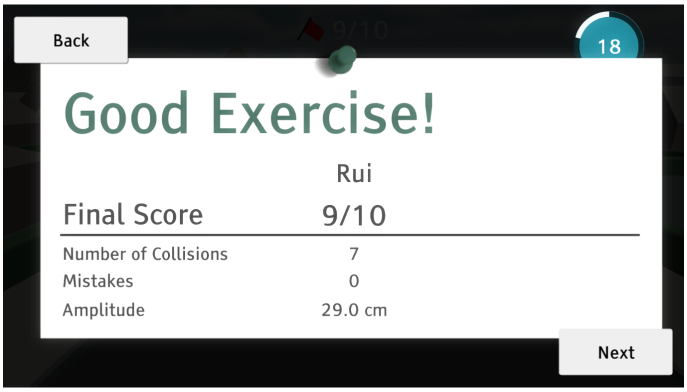


Figure 4.14: Segway Stroll scores.

player that he was not supposed to advance when the traffic light is red or a car is crossing the street.

As for the score screen, it presents the number of surpassed checkpoints as the final score and also the number of obstacle hits, the number of times the player mistakenly advanced through the street, i. e. crossed the street with red light on or when a car is crossing as well, and the total COP's amplitude in the AP direction as a evaluation metric The figure 4.14 shows a possible outcome from playing Segway Stroll.

4.3.5 Exercise Analysis

In order to evaluate the forward reaching exercise, therapists usually measure the maximum distance the patients can reach with their arm. This analysis is hard to assess using the WBB. Nevertheless, the system collects the maximum distance the COP reaches in the AP direction and presents it to the user in the score screen.

The purpose of traps in this game is to force the player to stand still for a few seconds. This way, quantitative metrics can be taken for further analysis as indicated by Duarte and Freitas [DF10]. However, the traps are activated for at most 10 seconds, instead of at least 30 seconds required for a correct assessment according to Duarte and Freitas [DF10]. This decision was made because seniors could get bored with the game if they had to stand for a long time, thus failing to motivate them to play. Figure 4.15 presents a COP's path chart, a COP's frequency map and a amplitude over time chart. All the examples were taken from a participant gameplay during test phase 2, which is described in subchapter 5.2. These metrics could provide data to physiotherapist so they can perform a balance assessment on their patients.

4.3.6 Game architecture

Segway Stroll can be seen in figure 4.16. It follows the same principles of the architecture of Scooter Chase. It has the same layer disposition and even uses the same WBB listener and Balance Assessment components. However, in this case, the Balance Assessment is connected to the logic

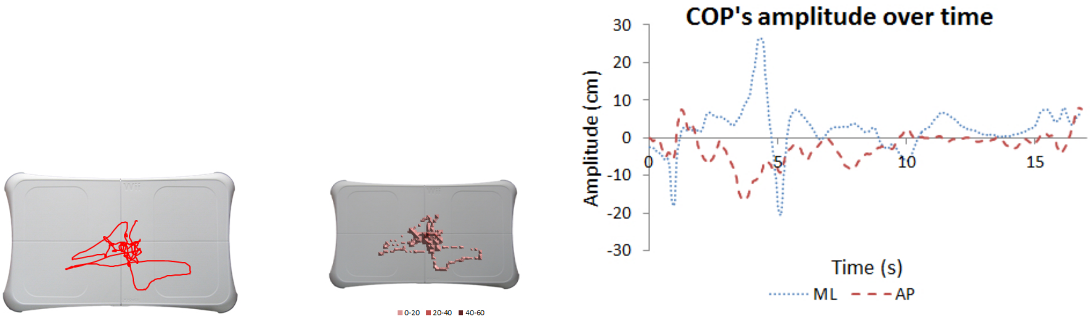


Figure 4.15: COP's path chart on the left, COP's frequency map on the center and COP's amplitude over time chart on the right while standing taken from Segway Stroll.

direclty, as none of the detectors are for standing position. The game logic component checks if no exercise is being made and if there is any trap active, which means the player should be standing and waiting for the trap to deactivate.

The segway control module receives data from the three detectors and determines how the segway should react. The trap controller will awake if a player is near it. In this situation, the player needs to stop moving until the trap deactivates. Otherwise, the user will have to wait one more time. The checkpoint controller will be activated in the same way as the trap controller. Then, the player may need to pass through the next checkpoint under a certain interval of time or it will disappear.

4.4 Summary

A balance assessment framework was developed that uses the WBB to measure the COP's mean velocity, total displacement, path, amplitude over time and frequency map. This assessment could be used by professionals do evaluate a patient's balance by distance.

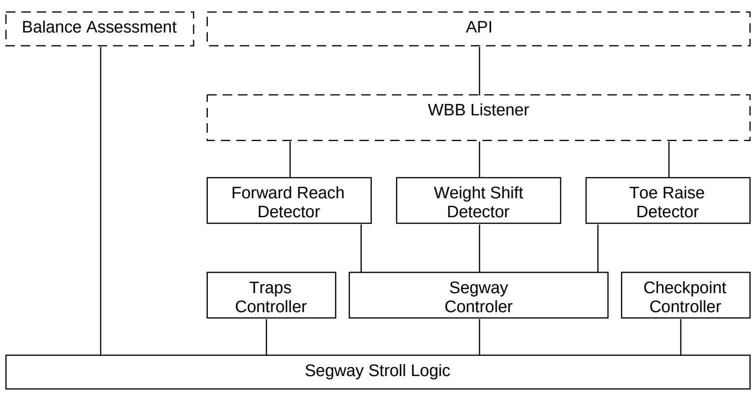


Figure 4.16: Segway Stroll Architecture.

The framework is used by two developed exergames from the proposed five in subchapter 3.3. While the user plays the games, which use exercises from fall-prevention oriented programs, balance assessment metrics are also computed. These exergames can motivate seniors to exercise regularly and at the same time evaluate their balance.

Chapter 5

Evaluation and Validation

The developed solution for this dissertation was tested in two separate times in order to evaluate this dissertation's research statements. In each test, volunteers with more than 60 years that lived independently interacted with the system on their own and answered a few questions after the experiment. This chapter describes both test phases methods and results.

5.1 Test Phase 1

The first test occurred on May 11^{th} and 12^{th} of 2015. In this test, a preliminary version of Scooter Chase was tested with older adults. The main goals for this phase were to test the usability and efficiency of the system. The following sections detail the test and its results.

5.1.1 Population

Six volunteers participated in this test. They were seniors who lived independently with age between 64 and 76 ($\bar{x} = 69.5 \pm 3.94$), four of them were of the female gender. Their technological expertise was quantified by the regular use of three devices: smartphones, computers or laptops and tablets. Two participants stated that they used all the devices regularly, two said they used only the smartphone and one used only the computer and the other does not use any of the devices regularly. This population's technological level has good variety which permits to test the usability on different people in this perspective.

5.1.2 Methods

Before the trials, participants had to sign a consent form. Then, after properly introduced to the test mediator, they were asked to interact with the developed game as follows:

1. Open Scooter Chase game from Smartfeet menu.
2. Read game instructions which appeared in the beginning.
3. Read the calibration instructions and proceed accordingly.

   (a) If the user does not know what to do, the mediator should explain.

4. After the calibration, the user should play the game as instructed in point 2 until it finishes.

   (a) If the user does not know what to do, the game should be restarted.

   (b) If the doubt persists, the mediator should explain the mechanics.

   (c) If the player does not understand the game goals, they should be explained by the mediator.

5. After playing the game, the user is presented with a questionnaire to reply.

This protocol provided means to determine the game's usability by detecting what users can or cannot understand. While playing the game, the system tracks the senior's COP for efficiency testing. The measured metrics are explained in the next section and the questionnaire is detailed as well.

5.1.3 Measured Metrics and Questionnaire

Three types of metrics were retrieved in this test phase. First, gameplay score metrics and the automatic measures described in Balance Measures, chapter(4.1), were taken while the seniors played the game. Second, as mentioned in the last section, a questionnaire was given to the seniors after playing the game. Third, manual annotation about the explanation level necessary for seniors to understand the game.

The game score metrics taken were the number of checkpoints reached, number of collisions with the scenery and the total game time. The automatic measures taken were the COP tracked while on tandem stance (only to draw the COP's path and frequency map for demonstration purposes), COP's total mean velocity and total oscillation. In addition the total time on tandem stance, number of repetition and for each repetition the time, COP's mean velocity, oscillation, standard deviation and variance were also taken. The COP's amplitude over time chart is not possible to draw for these tests as time was not yet being written in the results file.

The questionnaire for this phase has two parts which are presented in tables 5.1 and 5.2. Age and the expertise level question are made to describe the population. The expertise level question was made to study if being accustomed to technological devices would affect the system's usability

Table 5.1: Questionnaire header with answers to characterize the population.

Age:		
Expertise level: Do you use any of the following devices regularly?		
Smartphone	Computer	Tablet

Table 5.2: Questions and possible answers player to fill for test phase 1.

Question 1: In general, do you think the Scooter game was easy to play?				
Strongly disagree	Disagree	Neutral	Agree	Strongly agree

Question 2: Check in which moments you had more difficulties:				
Calibration	Control the scooter	Catch the cat	Avoid obstacles	Locate the cat

or the balance assessment results. The participant's expertise is measured by the number of devices regularly used. The question 1 is asked to perceive the exergame usability and the question 2 is for the developer to know what aspects to improve. Question 1 answers determines the volunteer's opinion on game difficulty whereas the number of answers on question 2 are the number of difficult moments.

Finally, the mediator took annotations to classify the explanation level the user needed to play the level in a scale from one to five as follows:

1. the user did not understand;
2. the user needed a demonstration on how to play;
3. the user needed an oral explanation;
4. the user understood when the game was restarted;
5. the user understood without help.

Table 5.3: Test phase 1 metrics summary.

Metric	Type	Description
Technological expertise level	Discrete	Number of devices regularly used according to table 5.1.
Number of difficult moments	Discrete	Total of option selected on question 2 of table 5.2.
Explanation level required	Discrete	Average of scores on table 5.4 topics.
Game's difficulty perception	Discrete	Table 5.2 question 1 answers.
COP's mean velocity	Continuous	COP's mean velocity while performing a tandem stance automatically measured by the system.

Table 5.4: Explanation required analysis topics.

#	Measured Topic	Scale	Explanation
T1	WBB calibration	[1,5]	How the user understands the WBB calibration process and then performs it.
T2	Smartphone calibration	[1,5]	How the user understands the smartphone calibration process and then performs it.
T3	How to move	[1,5]	How the user understands that is needed to perform a heel toe standing on top of the WBB in order to move.
T4	How to turn	[1,5]	How the user understands that rotating the smartphone will make the scooter to turn.
T5	Must catch the cat	[1,5]	How the user understands that the game's main goal it to catch the cat.
T6	How to locate the cat	[1,5]	How the user understands that the arrow point to the cat's direction.

The topics subjected to evaluation with this scale are described in table 5.4. These annotations provided usability information without asking testers to answer more questions. The average of all topics is the explanation level required for each participant.

A summary of all the metrics can be found in table 5.3. The results for all the tests are in the next section.

5.1.4 Results

The mean values to the answers to the first question and the explanation level required to play the game are presented on the chart of figure 5.1. The automatic measures taken from the system are presented on table 5.5. The COP's path and frequency charts are presented in appendix A. The remaining answers to the questionnaire will be stated textually in this section.

Starting with the required explanation analysis, it can be seen that the participants did not have trouble with the devices calibration and knowing how to turn. As the movement instructions were in the beginning, even before the calibration, users would not remember how to move or would not read at all. Then, when they were supposed to start playing, they did not know what to do. The images were very small and participants would not understand the stance they should adopt. No objective explanation was given to the participants that confused them even more. They ignored both cat and arrow until the mediator explained what the player should do with those elements. It was concluded that the game should provide an objectives' explanation following the instructions and this phase should be presented after the device calibration.

In the first question, if the game was easy to play, seniors answered either "agree" or "disagree" which did not favor the game's usability. However, this difficulty could be more related to the

Table 5.5: Automatic measures for each participant in test phase 1.

Gender	Age	Stance Time (s)	Mean Mean Velocity (cm/s)	Total Oscillation (cm)	Tech. Expertise	Difficult Moments
F	69	52.6	3.5	170.7	1	4
F	68	60.0	15.3	1004.0	3	4
F	76	55.3	21.2	1134.0	0	3
M	64	25.1	12.7	329.2	1	5
M	71	60.8	6.5	495.2	1	4
F	69	48.0	6.3	326.4	3	3
Average		50.3	10.8	568.4	1.5	2.3
STD Dev		13.2	6.7	399.6	1.2	1.4

instructions and objectives apprehension already stated than with the gameplay itself. One of the participants commented that "the game was easy once I understood what I had to do". In conclusion, the gameplay itself is appropriate, but the instructions and objectives' explanation must be improved for the players to understand the game.

When asked in which moments they had more difficulty, four chose catching the cat, four chose avoiding obstacles. While one participant selected all moments, only another participants chose controlling the vehicle and locating the cat and did not relate to difficulties in catching the cat and avoiding obstacles. This makes unclear from the questionnaires what causes those main difficulties. It could be the cat's size that made difficult to catch and the fact that it stops on place with some obstacles around that made the participants hit them. Nevertheless, comparing to the

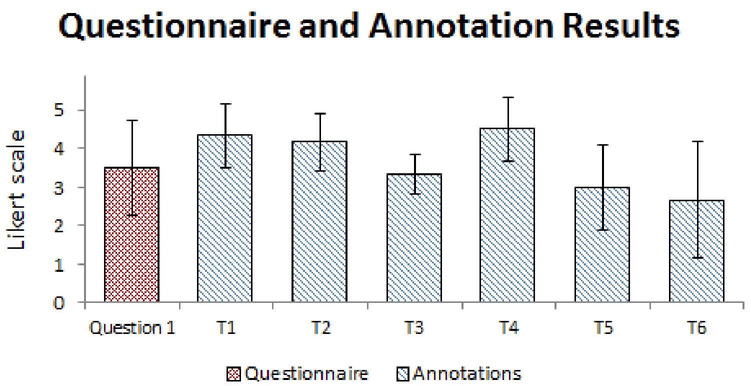


Figure 5.1: Test phase 1 questionnaire and explanation level required average results.

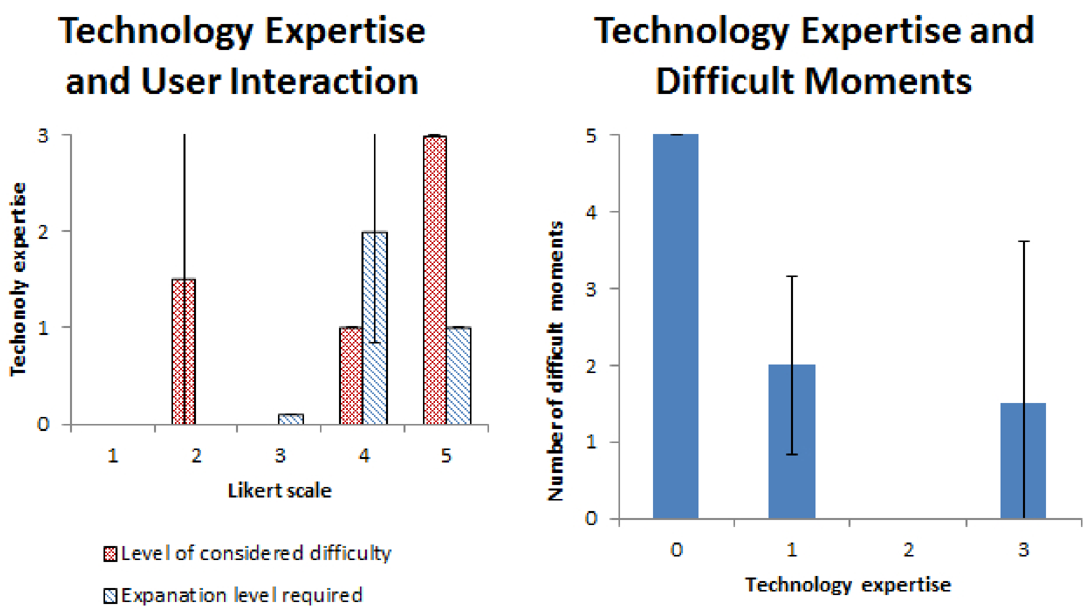


Figure 5.2: Average technological expertise for each explanation level required to play and opinion about the game's difficulty (left). and expected by number of difficult moments by technological expertise expected (right).

explanation level analysis, not knowing how to locate the cat could be the reason why catching it was hard. Two participants claimed they had difficulties calibrating the devices despite they did not require help. They could have misunderstood the question, however.

Lastly, the automatic measures taken shown that these participants had no difficulties performing the tandem stance as they could maintain the pose through the game. The participants with 25.1 s and 48 s of stance time were the ones who completed before the time ran out, which is why they have less time than the others. The relation between time, mean velocity and oscillation is clear in the table as the latter increases if the other two increase. Thus proving consistency. However, this data should be further studied with physiotherapists to prove their quality.

5.1.5 Statistical Analysis

The test metrics results were compared in order to obtain early conclusions or patterns. As the sample was small, the results hardly suggest some patterns may exist. In this analysis, technological expertise and gender was compared with the number of difficult game moments, the explanation required to play the game, the game's enjoyment and the COP's mean velocity. In addition, the COP's mean velocity was also evaluated with the number of difficult game moments and the explanation required to play the game. The explanation required to play and the opinion on game's difficulty are scales where higher values means easy to understand or easy to play respectively. In the number of difficult moments, however, higher values mean the contrary.

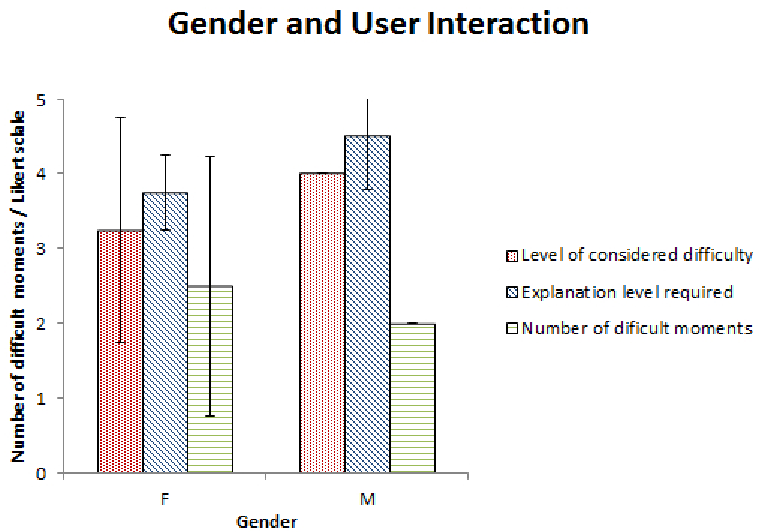


Figure 5.3: Number of difficult moments, opinion on game's difficulty and explanation level required by gender.

On figure 5.2 left chart, it is presented the relation between technological expertise and both opinion on game's difficulty and explanation level required to play. The technological expertise is the number of devices the participant regularly uses, between smartphones, computers or laptops and tablets, the explanation level required to play the game is measured by the average of score in the annotation's topics described in section 5.1.3, Measured Metrics and Questionnaire, and the level of considered difficulty is the answer to question 1 of table 5.2, as stated in table 5.3.

The results in chart 5.2 suggest that seniors more accustomed to technology find the exergame easier to be played whereas participants with less expertise have more difficulty to understand the game. The ability of maintaining the heel toe stance without effort also interferes with the results as the volunteers who struggle more find the game more difficult, thus, results are not linear. Participants stated they used zero, one or three devices and this also interferes with the linearity of the results. Nevertheless, these preliminary results show a potential correlation between technological expertise and difficulty in playing and understanding the exergames.

Figure 5.2 right chart shows the technological expertise with the number of difficult moments. The number of difficult moments is the number of selected options in question 2 of table 5.2, as stated in the metrics summary in table 5.3

Results of both charts in figure 5.2 suggest that the less the participant is used to technology, more difficult moments will appear and more difficult the game will be perceived by the users. These results may have influence from difficulty in performing a tandem stance that makes more difficult to control the scooter or to concentrate in the game. Nevertheless, these results show a potential relation between being accustomed to technology and number of difficult moments found during the game and difficulty in understanding and playing the exergame.

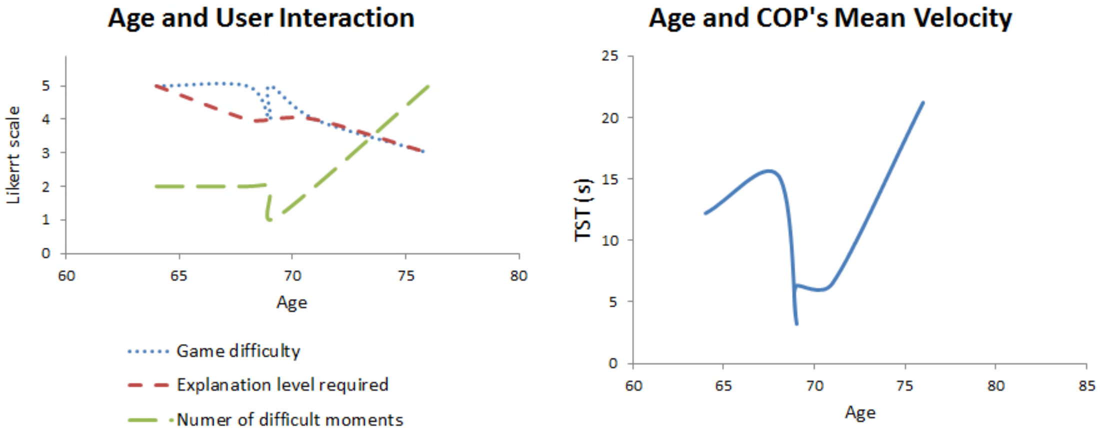


Figure 5.4: Technological expertise, opinion on game's difficulty and number of difficult moments (left) and COP's mean velocity while performing a tandem stance by age.

The chart in figure 5.3 presents the relation results between gender and usability metrics. Although the charts suggests the volunteers of the male gender performed slightly better than the volunteers of the female gender, this difference is small, thus no conclusions can be made. In addition, these results may be influenced with other factors, such as age and technological expertise, as there were only two participants of the male gender and one of them was the youngest participant.

As stated above, age could also explain some relations obtained. Although the sample is small and four participants have age between 68 and 71 years old, the chart on the left of figure 5.4 suggests that age influences the players' performance, as by ageing the user would have more difficult moments, find the game more difficult and understand the game worse. This results appear more suggestive than those of figure 5.2 where the same metrics are compared with the technological expertise level.

When comparing the COP's mean velocity with age, the curve seen on the right chart of figure 5.4 has a erratic behavior where early participants with the two youngest and the oldest participants presented more COP's mean velocity during the tandem stance than the other three. This evaluation suggests that ageing alone does not affect the COP's mean velocity during the tandem stance.

The last charts are related to COP's mean velocity during the tandem stance. On figure 5.5 is presented the relation between technological expertise on the left and gender on the right. On figure 5.6 COP's mean velocity is related with the number of difficult moments and the explanation level required

The results on the left chart of figure 5.5 suggest that users less accustomed to technology have more COP's mean velocity as it drastically descends between expertise levels 0 and 1. However, it rises on level 3. This evolution could be more related to age, as the participant who scored 0 on technological expertise is also the oldest of the participants.

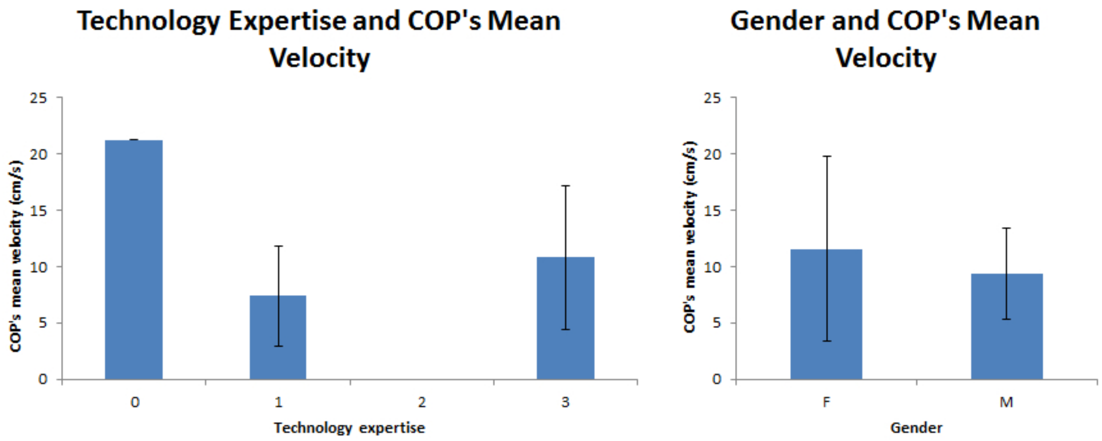


Figure 5.5: COP's mean velocity, while performing a tandem stance, by technological expertise (left) and gender(right).

Finally, chart on figure 5.6 suggests a relation between difficulty and COP's mean velocity where the higher the number of difficult moments or lower the required explanation level, the higher was the COP's mean velocity. This could happen due to age, as the older participant was the one with most difficulties while the others had a similar score.

5.1.6 Discussion

This test revealed the strong and weak points of the system at that date. The calibration instructions were enough for the players to follow while the movement instructions were badly placed as the users ignored them in the first time and would not know what to do. Objective's instructions are needed as the participants did not understand what they were expected to do. Nevertheless, once players understood the task, they found the game easy to play.

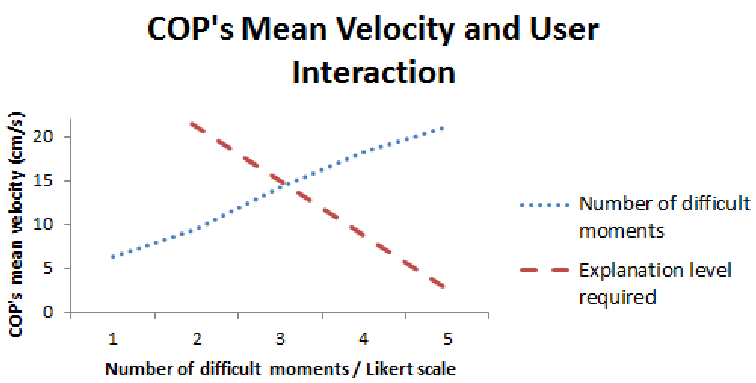


Figure 5.6: COP's mean velocity by number of difficult moments and explanation level required.

Crossed analysis demonstrated that participants more accustomed to technology could understand and play the game more easily. On the other hand, understanding and having less difficulties during the game results in better balance performance, less COP's mean velocity, thus technological expertise could condition balance performance. However, this test has a small sample. These results were further studied in the second test phase.

5.2 Test Phase 2

The second test occurred on June 8^{th}, 9^{th} and 11^{th} of 2015. This test focused on the system's usability and satisfaction. The volunteers experiment the final versions of Scooter Chase and Segway Stroll. The next sections describe this test's methods and results.

5.2.1 Population

This test phase counted with participation of eleven participants. These volunteers were seniors who lived independently with age between sixty-four and eighty years old ($\bar{x}$ = 72.09±5.75). Six participants were of the female gender. The technological expertise for this population was characterized by their regular use of smartphones, tablets and computers or laptops, similar to test phase 1. Three participants said they do not use any of the devices regularly, two stated that they used the smartphone and two other said they used smartphones and computers. From the remaining participants, one said he uses only computers, another uses only the tablet, the third uses the smartphone and the tablet and the last said he uses all the devices regularly. This group has great differences about their technological habits, which allowed to test which segments are more open to the use of exergames and if the game instructions are perceived by everyone.

5.2.2 Methods

Before interacting with the developed exergames, the volunteers signed a consent form. After the signing, the mediator asked the participant to perform the TUG test. Then, the participants would experiment system following the instruction of a mediator. The mediator instructed the volunteer as follow:

1. Perform the TUG test.
    - Begin seated.
    - When the mediator says "go", get up walk three meters, return and sit again where the participant was.
    - The three meters distance is pointed out by the mediator.
    - The mediator must start a stopwatch when saying "go", stop when the participant sits and write the time.
2. Play the Scooter Chase game.

- Read the calibration instructions and interact accordingly.
- Read the game instructions and play the game.
- If the player does the calibration wrong or does not understand something, the game should be restart.
- If the player has not understand, the mediator should explain or demonstrate the instructions.

3. Play the Segway Stroll game.
   - Read the calibration instructions e interact accordingly.
   - Read the game instructions and play the game.
   - If the player does the calibration wrong or does not understand something, the game should be restart.
   - If the player has not understand, the mediator should explain or demonstrate the instructions.
4. Answer the questions on the questionnaire.

This protocol provides a balance test result for comparison with the automatic system analysis to evaluate if the system assessment was consistent. The games' evaluation approach is similar to that of the first test phase, oriented to usability evaluation. The questionnaire has questions about physical exercise habits and motivation to play these games. All the measured metrics are described in detail in the next section.

5.2.3 Measured Metrics and Questionnaire

Similarly to test phase 1, three kinds of data were retrieved: data collected from the system while the user was playing, both balance measures, questionnaires filled by the user and annotations from the mediator.

For the Scooter Chase analysis this data was taken from the system: total time in tandem stance, maximum time in tandem stance (which is used by the system to evaluate the player's balance using the TST [HBP+12]), COP's mean velocity and total oscillation through the game, the number of repetitions, for each of them, the standard deviation and the variance in AP and ML direction and lastly, COP read while in the stance and the time it was taken, used to draw the COP's path, COP frequency map and COP's amplitude over time.

From the Segway Stroll, the system tracks the COP's when the player is standing still for more than 10 seconds. It records all COP readings and respective time during the tracking in order to draw the COP's path, COP amplitude over time in AP and ML directions and a frequency map. In addition, it was recorded the COP's total mean velocity, total oscillation, standard deviation and variance.

Table 5.6: Test phase 2 metrics summary.

Metric	Type	Description
Technological expertise level	Discrete	Number of devices regularly used according to table 5.1.
Explanation level required	Discrete	Average of scores on table B.2 topics.
Games' difficulty perception	Discrete	Average of table B.1 last three questions answers.
COP's mean velocity	Continuous	COP's mean velocity while performing a tandem or standing stance measured by the system.
TST	Continuous	Maximum time maintaining a tandem stance.
TUG	Continuous	Results from TUG test.

The questionnaire's questions and possible answers are presented in table B.1 on appendix B. In addition to those, the questions in table 5.1 are included to describe the population. The first question in table B.1 is another background question relative to exercise practice. The five following questions are related to enjoyment in playing the exergames, motivation to exercise through the use of them and also if they felt they were doing any effort during the test. The last three questions focused on usability and which topics needed improvements.

The annotations taken by the mediator followed a similar style of the test phase 1, with a scale from 1 to 5 where each value mean:

1. the user did not understand;
2. the user needed a demonstration on how to play;
3. the user needed an oral explanation;
4. the user understood when the game was restarted;
5. the user understood without help.

The topics list for explanation required to play evaluation was larger than the last phase, as the usability of two game were tested. The evaluation topics are described on table B.2 of appendix B. Once again, these annotations were taken to collect information about the games' usability without subjecting the user to too many questions. In addition, the TUG test result was also annotated by the mediator for a balance background. The results for all the tests are in the next section.

A summary of all metrics used in the tests is described on table 5.6.

5.2.4 Results

In this subchapter are presented the results obtained in the second test phase. Mean values of the answers to the questionnaire can be seen in the chart on the figure 5.7 while the the explanation

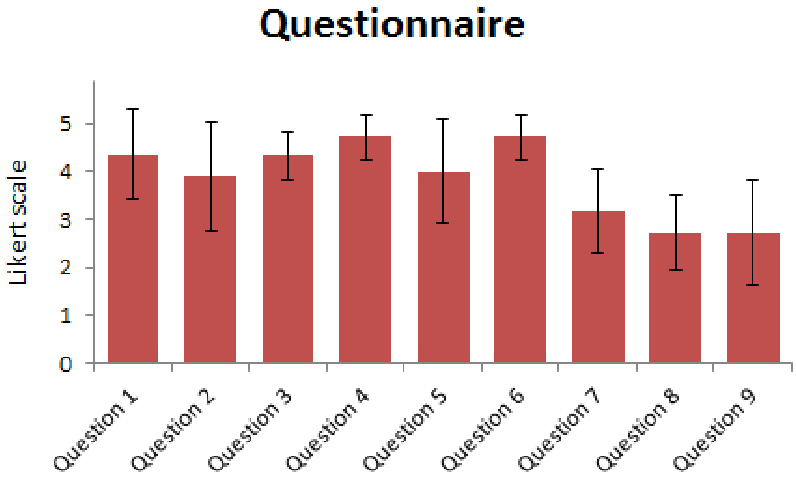


Figure 5.7: Test phase 2 questionnaire average results.

level required to play the exergames in figure 5.8. The average of the TUG result and automatic retrieved answers are presented in table 5.7. The COP's path, amplitude over time and frequency charts are presented in appendix C for the tandem stance while playing Scooter Chase and in appendix D for the standing stance while playing Segway Stroll.

Unfortunately, during this test phase the WBB data received by the system may not have been correct due to technical problems. When tested with WiiYourself[1] program, total weight values were not correct and sensor readings were negative when pressed. This situation could have been caused due to problems with WBB calibration. However, the tests were made as the required exercises were being detected, with the exception of two participants who could not play Segway Stroll, though it could be the detection that was not fit. Nevertheless, the data was retrieved from the system to compare with the results of the TUG test. Few participants had their standing stance

[1] WiiYourself, library to communicate with WBB, http://wiiyourself.gl.tter.org/

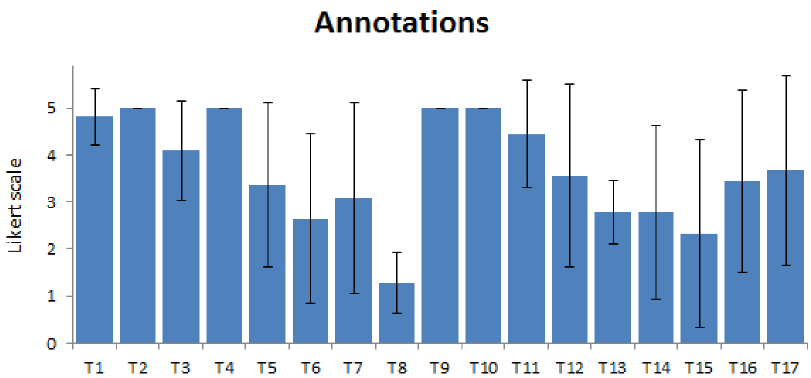


Figure 5.8: Test phase 2 explanation level required average results.

Table 5.7: Automatic measures for each participant in test phase 2.

				Tandem Stance			Standing Stance	
Gender	Age	Tech. Expertise	TUG (s)	Time (s)	Mean Velocity (cm/s)	Total Oscillation (cm)	Mean Velocity (cm/s)	Total Oscillation (cm)
F	80	0	15.0	33.9	10.7	837.6		
F	66	2	8.3	35.3	25.2	1778.6		
M	64	3	5.6	54.2	27.7	1757.6	6.2	92.1
F	67	2	5.0	61.7	81.6	932.9		
M	77	2	9.7	118.0	34.3	1482.5	14.3	181.8
F	69	0	5.0	149.9	7.6	1236.6	16.3	308.7
M	78	1	6.2	96.9	18.2	1319.7		
M	68	0	4.6	14.3	10.3	571.4	9.6	237.4
F	76	1	12.7	103.5	24.1	1731.7		
F	78	1	8.5	41.1	9.7	1367.4	8.9	72.9
M	70	1	10.4	41.9	12.6	825.9		
Average		1.8	8.3	68.4	23.9	1258.3	11.1	178.6
STD Dev		1.0	3.4	42.5	21.1	418.6	4.1	98.8

assessed by the system for two reasons. First, almost all participants thought they had to raise their calves, as in portuguese toes would be translated to *pontas dos pés*, literally feet tips which can work to calves as well. One participant after corrected stated "indeed, in the image is also raising the toes". Second reason was difficulties in doing a acceleration-brake movement and not being able to surpass the first trap before the time ran out.

All participants scored less than 20 s in the TUG test as expected for older adults who live independently [PR91]. With the exception of one participant, all seniors scored more than 30 s in the TST which indicates the same lack of balance impairments [HBP+12]. In the exceptional case, the participant stopped the stance many times to stop the scooter and figure what to do and not because he could not maintain the position.

Observing the explanation level charts, it suggests the calibration methods were well understood by seniors. The how to move instruction in Scooter Chase was also well understood by all participants which suggests the order change determined by last test results was well designed. However, the turning instruction was less efficient than on the last test, which may be the result of too many instructions in the beginning of the game. The game objectives continued to be hard to understand by the seniors, most of the participants did not catch the cat a single time and ignored

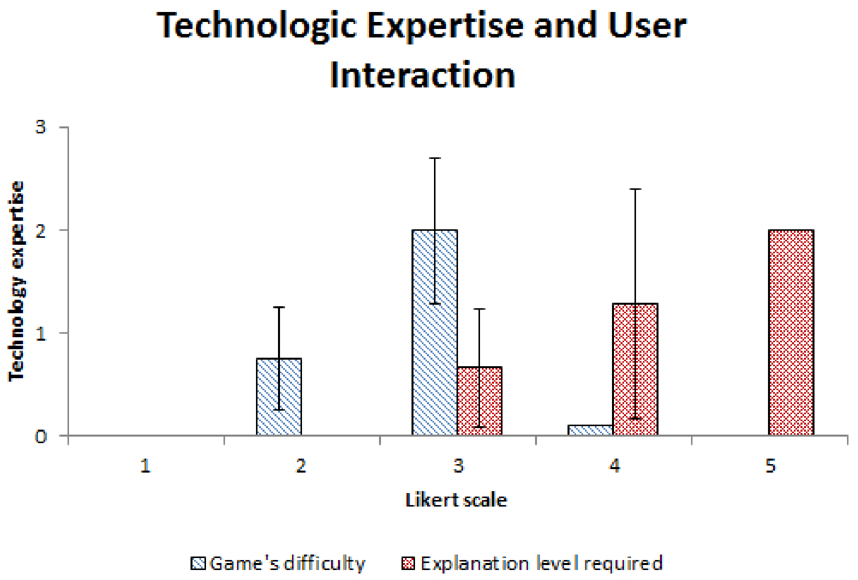


Figure 5.9: Technological expertise for each games' difficulty and average of explanation level required to play on test phase 2.

the arrow's direction that pointed to the cat. For the Scooter Chase game to be played by seniors, they need demonstrations, training or a much simpler interface.

As for the Segway Stroll game, the main problem was the braking mechanism, as already stated, where the participants would do the incorrect exercise, causing most users to not surpass the first trap. In addition, most users ignored the checkpoints flags and the time given to reach it. Finally, avoiding obstacles and traps was well understood, despite not being able to avoid both sometimes. Nevertheless, participants played this game better than Scooter Chase, but demonstration and training could help seniors understand the objectives better.

All volunteers, except one, said they practice exercise regularly in the first question. Some even commented what exercises they usually do, such as gymnastics or tai-chi. The results of TUG and TST may be derived from this practice. Despite the obvious difficulties in playing these games, most seniors claimed they liked Scooter Chase, all seniors who had opportunity to play Segway Stroll also enjoyed the game and all the seniors said they would like to play these games regularly and by doing so, it would motivate them to do exercise. Most seniors also stated they felt they were doing physical exercise or efforts. The last three questions were focused on the usability and received less favorable answers as expected by the explanation required to play analysis.

5.2.5 Statistical Analysis

In this phase, a similar analysis as the first phase was done between metrics. First, the technological expertise level was compared with difficult and balance performance metrics through the

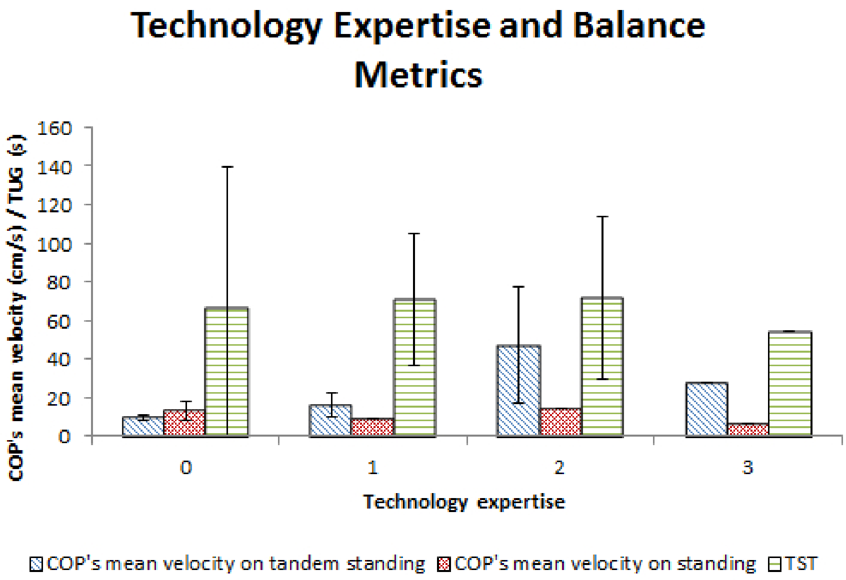


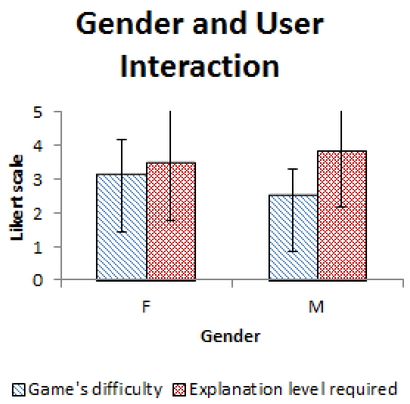
Figure 5.10: Maximum tandem stance time and COP's mean velocity during the tandem stance and standing stance by technological expertise on test phase 2.

gameplay. Then, gender was crossed with the same metrics and games' difficulty and explanation required to play the game was crossed with balance performance. In addition, age was also crossed with difficult and balance performance metrics. Lastly, a comparison between balance metrics including TUG, was made.

Technological expertise is, once again, quantified by the number of devices regularly used. The games' difficulty is the average of the answers to the last three questions of the questionnaire, with the higher the score, the easier it is to play. The explanation required to play the game is the average of scores given following the annotation topics described on section 5.2.3, Measured Metrics and Questionnaire, with higher scores meaning they understood with less explanation given.

Technological expertise related to games' difficulty and explanation level required charts can be seen in figure 5.9. Although participants who rated the game as easier did not use devices regularly, the others scored the games easier higher according to their technological expertise level. Moreover, when compared with the required explanation level, the more accustomed participant's were with technologies, the better they understood the instructions. This analysis suggests that users more accustomed to technology can understand better the games' instructions as observed in the first test phase. However, the opinion on games' difficulty may be independent of the expertise level. Other factors can be more prominent in the opinion on the games' difficulty such as struggle in doing the exercises.

Balance performance compared with technological expertise can be seen in figure 5.10. Only one participant claimed that he used the three devices regularly and he scored less in TST comparing to the average of the other groups but also scored less in the COP's mean velocity during the



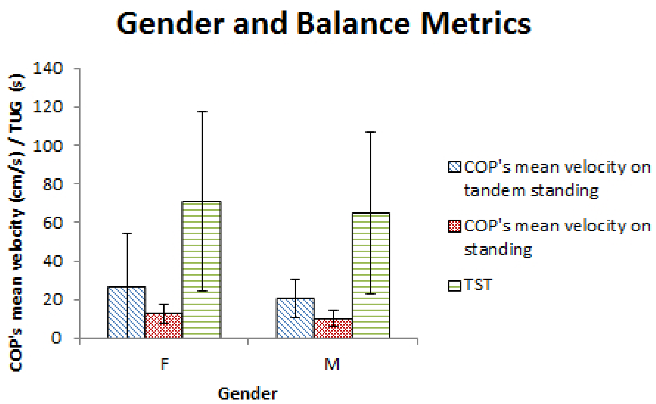
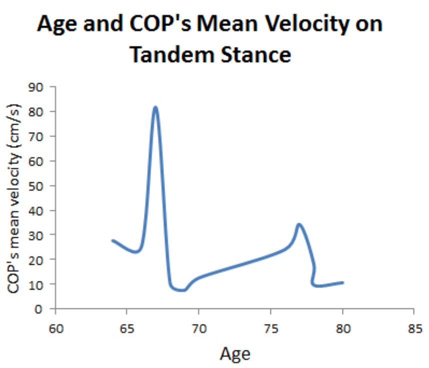


Figure 5.11: Games' difficulty and average of explanation level required to play (left), COP's mean velocity during the tandem and standing stance and maximum tandem stance time (right) by gender on test phase 2.

tandem stance than users who use two devices and during the standing stance comparing with all groups. For the rest, the results suggest TST performance slightly improves with higher technological expertise, however, COP's mean velocity during the stance rises. As only one participant who scored two on the technological expertise level could play Segway Stroll, results suggest COP's mean velocity during the standing stance lowers with higher habituation to technological devices. Thus, technological expertise may not affect balance performance.

Gender comparison brought different results when crossed with difficulty and with balance performance metrics as seen on figure 5.11. Although participants of the male gender classified the games as harder than participants of the female gender, they required less explanation to play the games. On balance performance, participants of the male gender scored slightly better on COP's mean velocity during both tandem and standing stances, they scored slightly worse on TST.

When comparing the levels of games' difficulty and explanation required with balance metrics,



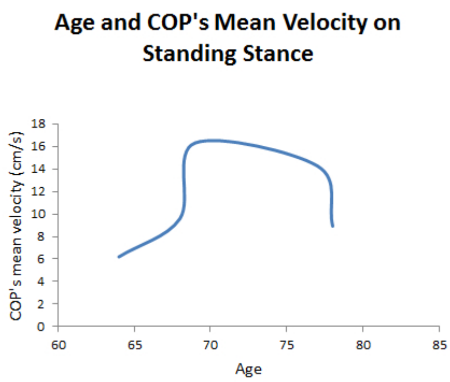


Figure 5.12: COP's mean velocity during the tandem (left) and standing stance (right) by age on test phase 2.

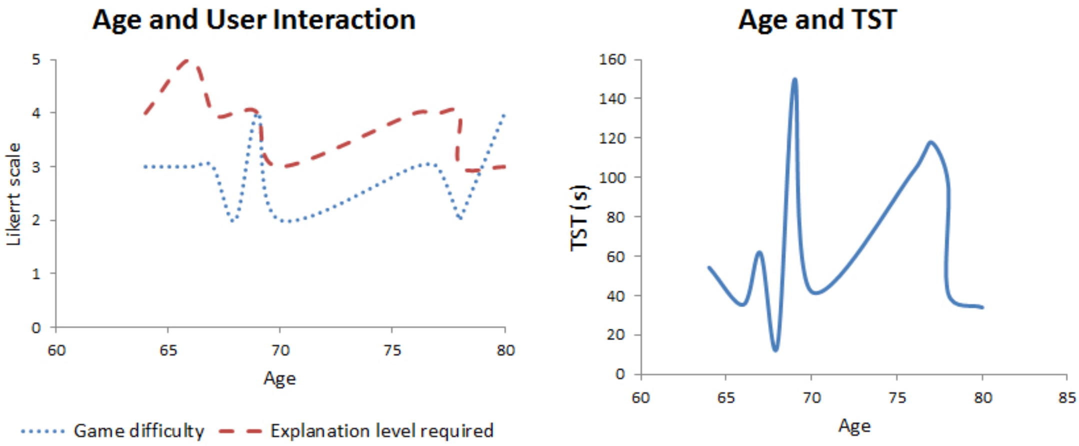


Figure 5.13: Games' difficulty and average of explanation level required to play (left), and maximum tandem stance time (right) by age on test phase 2.

also seen in figure 5.11, it is suggested that users that think the game is easier perform better on TST while users who understand the game better higher COP's mean velocity when maintaining a tandem stance. This means that the ability to maintain the tandem stance position may affect the user's perception of the games' difficulty while the users that understood the games better were more vigorous when performing the stance. The comparison also suggests that the easier and understandable the game is, the higher will be the COP's mean velocity when standing. Few participants could be assessed while playing the Segway Stroll, thus the COP's mean velocity rise may be caused by other factors.

Age comparison, seen on figures 5.12 and 5.13, gave out erratic results. In the first chart is described that users with less than 70 years old in this sample understand the games better. The other three charts is described that age did not affect balance maintenance in participants with more than 64 years in this sample. The results from these charts suggest that there may exist relations between the three balance measures which will be evaluated next and again between game difficulty and maximum time maintaining a tandem stance and lowering the COP's mean

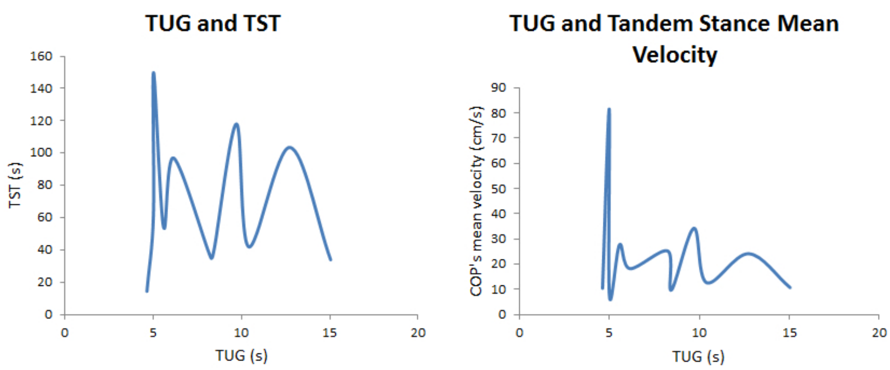


Figure 5.14: TUG compared with TST (left) and COP's mean velocity in tandem (right).

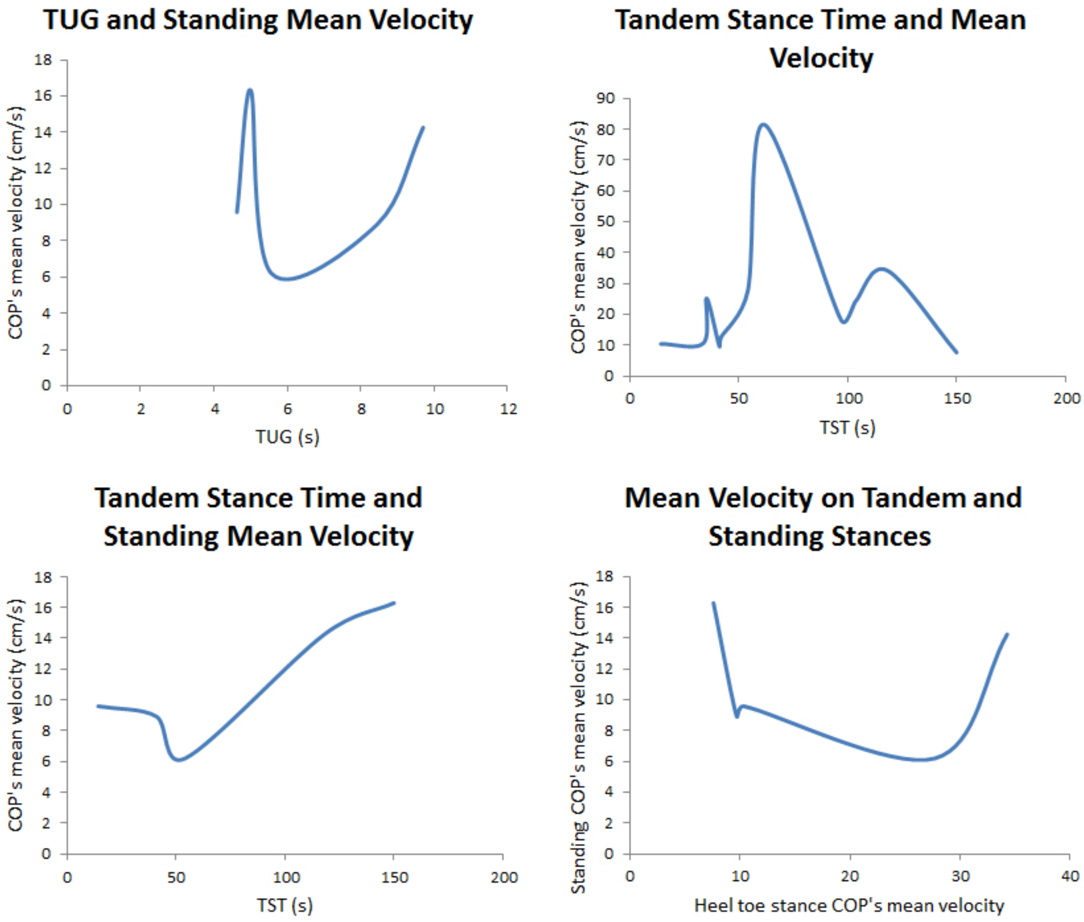


Figure 5.15: Standing stances (top left) and tandem standing time and COP's mean velocity comparison (top right) and COP's mean velocity while standing by TST (bottom left) and COP's mean velocity while on tandem stance (bottom right).

velocity during a standing stance. Other relations do not stand out.

Finally, a comparison between the balance measures results, including the TUG, was done to validate them. The resulting charts of crossed results can be seen in figures 5.14 and 5.15. As stated, the qualitative analysis of TUG and TST results match except in one circumstance, where the player was stopping regularly due to gameplay purposes. In TUG, all participants scored less than 20 s, which means they had no balance difficulties [PR91], and all but one scored more than 30 seconds in TST, which means high performance [HBP+12]. Comparing the times from both tests, however, does not reveal any correlation. This could happen because these scales were developed to detect balance impairments, which was not the case. When analysing the TUG and COP's mean velocity, the tests suggest that higher TUG results may not mean low mean velocities in healthy individuals. The same is not true to the comparison with TUG and COP's mean velocity during a standing stance, in which after 5 s, the more the TUG result rises, the more the COP's mean velocity also rises, here behaving as expected.

When crossing the automatic measures with each other, the results are also irregular. TST crossed with COP's mean velocity during the respective stance maintenance time results in a curve with erratic behavior, while crossing with COP's mean velocity during the standing stance shows a direct relation which would not be expected. Lastly, the relation between the COP's mean velocity during both stances turns into an indirect relation which would also not be expected. Nevertheless, with a larger sample it could be possible to reach other results, as outliers impact would be smaller.

5.2.6 Discussion

Test phase 2 gave mostly positive results concerning the dissertation's research questions. First, the participants claimed they enjoyed playing the games and they would like to do it regularly, showing motivation towards regular exercise practice. TST, COP's mean velocity, total oscillation, path, amplitude over time and frequency map can give a mean for physiotherapists and care-takers to supervise the elderly adults who play the games, thus it can be practicable. Frequent exercise has benefits, so it is expected that regular exergaming sessions would have to. Exergames have to be further studied to reveal their practicability to monitor patients' balance and benefits related to Fall-Prevention.

A comparison between traditional ways of exercise and exergames was not made. Most participants stated that they do practice exercise and they felt they were doing exercise during the tests. This suggests the participants put an effort in order to play the games better. Confidence was also not tested. By observation, the participants did not look confident when playing as most did not fully understand the games. However, they claimed they enjoyed the games and they were easy.

Relatively to the first test phase, the movement instructions in Scooter Chase were better understood, but the objective instructions were not so understandable. A better approach should be studied. The technological expertise once again showed to affect the players' understanding and difficulty perception through the game. However, this test refutes the idea that says being accustomed to technology affects balance performance.

Segway Stroll was tested for the first time. The game instructions were considered good, with the exception of the toe raises problem. The forward reaching detection algorithm was badly configured as some players had difficulty to move the character. This happened as the tests during implementation were made by the developer. Another difficulty was to avoid traps. As this was the first interaction with the system, players were not expecting the traps and did not stop in time. Then, the participants had problems doing a quick acceleration and braking immediately.

Age analysis suggests that after 64 years it is not directly related with balance maintenance. As almost all the participants exercise regularly, this result is not surprising. Quantitative balance comparison between metrics did not find any relevant relations, as the metrics used are more related to find balance impairments than to quantify balance in healthier individuals. Further testing these measures with physiotherapists may help reach additional conclusions. Nevertheless, qualitative measures between TUG and TST did obtained similar results, which indicates that this metric could be used to supervise the players.

5.3 Summary and Final Discussion

Two sets of test were made involving a total of 17 senior volunteers in which they had the opportunity to interact with the developed system. The participants were healthy and lived independently and most of them were exercised regularly.

The participants claimed that they have enjoyed the games and would like to repeat the experience regularly, concluding that exergames could lead older adults to healthfully exercise regularly and eventually decreasing fall risk. The volunteers also stated that these games motivated the physical exercise practice and they felt they were doing physical efforts during the game. This suggests they exercise with more effort in the present of exergames.

Finally, balance assessment measures were taken. Here, the results of the TST and TUG test did co-relate although all seniors obtained good results in both tests. Other metrics were also taken, but no relation was found. This assessment can be further studied to validate its usability.

Chapter 6

Conclusion

HCI and digital games towards rehabilitation are an important topic of research nowadays and multiple works have presented positive results in using recent motion sensing devices in therapy despite being originally created for entertainment as revealed in chapter 2. This dissertation takes advantage of these results, developing exergames to supervised home fall-prevention. This dissertation's results state that this orientation brings motivation to regular exercise practice, may benefit and could be practicable to decrease fall-risk in elderly adults and to supervise their balance evolution with metrics measured automatically during gameplay. This dissertation's balance was positive and opens doors for further research in fall-prevention exergames with balance assessment.

This chapter concludes the dissertation's document and makes a summary of what was accomplished, further work and recommendations.

6.1 Objectives Fulfilment

Recapitulating the objectives, they were to develop an exergame application fit to be played by older adults with specific exercises to fall-prevention, provide balance assessment metrics computation in order to provide a mean for supervision of the player's balance and evaluate both motivation to practice exercise through the use of the developed application and the balance assessment.

After researching possible exercises to detect with the WBB in fall-prevention oriented exercise programs and balance assessment scales, five different interactive exergames were designed and two of those were developed, named Scooter Chase and Segway Stroll. In the first, the seniors have to perform a heel-to-toe stance, present in OTAGO [CR03], FAME [EDP06], BBS [BWDWG89] and TST [HBP+12]. In the second, the players need to perform a forward reach, FAME [EDP06], Melo's exercise program [Mel08], BBA [Tys04] and FBA [RLW06], and toe raises as well, OTAGO [CR03] and FAME [EDP06]. This is the succinct summary of the developed exergame.

Several balance metrics were included to be computed while the user plays the games. They are the maximum time in the heel toe stance [HBP+12] and COP's mean velocity, total oscillation, path and amplitude [DF10], where the last two are charts. In addition, standard deviation, variance and frequency map, the last also a chart, are also implemented for more evaluation. This fulfills the dissertation's second goal.

Two separate sets of tests were made with a total of 17 volunteers. All participants stated they enjoyed playing the games, would like to do it regularly and that the games motivate physical exercise practice. This corroborates that home exercise through the use of exergames is motivating. Some participants commented "this is entertaining and makes us do exercise at the same time", "I don't like digital games with buttons, but I enjoy this", "most colleagues at day care are always playing cards and checkers; this would be better". The system TST qualitative results is related with the TUG test results which indicates that the system balance analysis can be used for supervision. Further studying with physiotherapists could validate this and all the other balance metrics, although automatic balance measures are proven to be computable. Longer sets of test, where the participants are given the opportunity to interact with the developed system for weeks or months should be done to determine the fall-prevention benefits and the system's practicability. This study could also compare the effort and longevity the players would employ during exergaming sessions and traditional ways and also the confidence they feel during and after each session. In the second test phase, most participants said that they felt physical exercise or efforts during the game which suggests they do more they to do more than usual to play better.

Uzor and Baillie [UB14] suggested that seniors do exert more effort when playing exergames than with a exercise program booklet and instructional videos. A similar test approach would be the ideal for the developed system, however, there was no time for it nor the resources needed to monitor several participants. Davies et al. in a similar work [DDS+13] observed that it was hard to monitor the player's balance performance because user's can learn how to manipulate the COP to trick the game. This was also seen during the tests, where in Scooter Chase, the players would not try to correct the heel toe position if the character was moving, even if it stopped several times for a few seconds. The movement detection algorithms must be rigorous but the user has to be committed as well, otherwise exercise benefits will not be obtained neither a balance assessment would be correct.

Exergaming has been show to have potential to improve traditional therapy exercises and fall-prevention exercise programs in works of Deutsch et al. [DBF+08], Geurts et al. [GVH+11], Uzor and Baillie [UB14], Davies et al. [DDS+13], Santos et al. [SGM+15] and other. This dissertation combines this research with HCI oriented to therapy works, such as Clark et al. [CBP+10] and Kennedy et al. [KSC+11] to create a supervised home exercise methodology. To the author's knowledge, this is the first study where a digital game combines fall-prevention exercises and automatic balance measures based on COP tracking.

6.2 Final Remarks and Future Work

The solution presented in this document shows great promises. It has potential to help prevent falls in the elderly, one of the world's top death causes [MGB07], motivating them to exercise with digital games. In addition, it could potentially help health professionals to do balance assessment at distance and supervise more patients through game progress and data that can be automatically retrieved. Reducing falls frequency and therapy sessions' costs can also reduce the economic impact of this problem. It may also be a market opportunity for digital games companies.

Two games were developed, but three more were designed that should be introduced in Smartfeet. Both Scooter Chase and Segway Stroll can be improved following the feedback obtained from the tests' participants. Difficulty levels could also be added to Segway Stroll, the same way they were to the other game. Movement detection could also be improved as it seemed appropriate when the developer tested, but not so much when the senior volunteers interacted with the system. Multiplayer games are also a development possibility as seniors seem to enjoy more a social activity, both cooperative and competitive [NSrY+14]. As stated above, the system can be further tested to evaluate the balance assessment metrics and the possible benefits from using it regularly over a long period of time.

For those who wish to invest in this area, the author recommends to work closer to the target population, as stated by Vines et al. [VPWO15]. This is the only way to check if the interface is simple enough, the algorithms are appropriate and the game playable and enjoyable. Even if that is not possible, the developer must not limit the tests to himself, since that would overly train the creators and consequently, they would made a game fit for them, but awfully challenging for the audience. Lastly, be patient as most elderly adults are not used to technology and some take advantage of test session to escape their routine.

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Appendix A

Test Phase 1 Balance Assessment Charts

In this appendix are presented the COP's path and frequency maps obtained while the participants performed a tandem stance, while playing the exergames Scooter Chase.

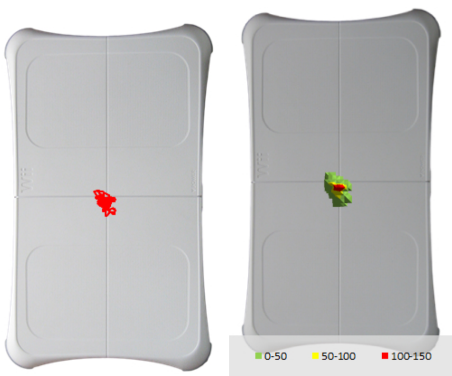

Figure A.1: Participant 1 COP's path (left) and frequency map (right) while playing Scooter Chase on test phase 1.

Test Phase 1 Balance Assessment Charts

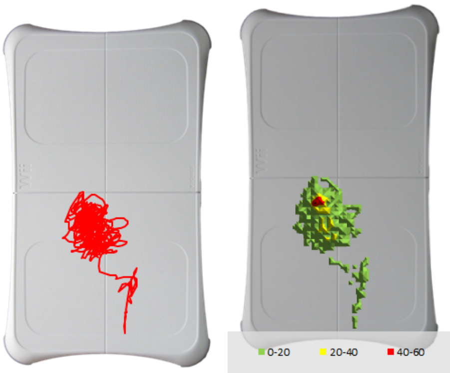

Figure A.2: Participant 2 COP's path (left) and frequency map (right) while playing Scooter Chase on test phase 1.

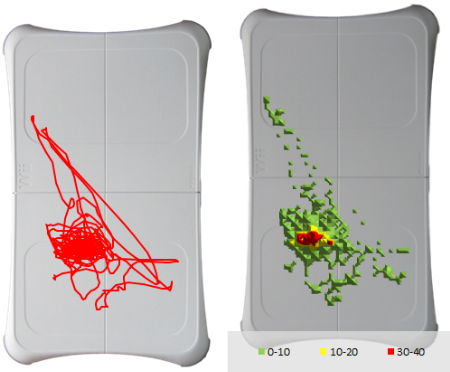

Figure A.3: Participant 3 COP's path (left) and frequency map (right) while playing Scooter Chase on test phase 1.

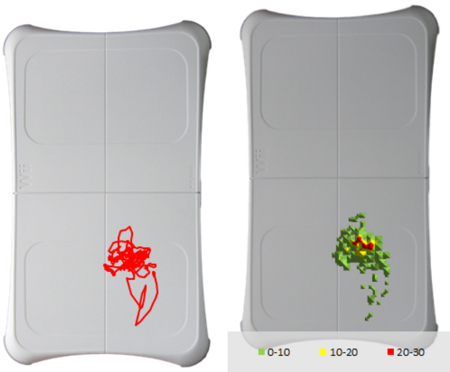

Figure A.4: Participant 4 COP's path (left) and frequency map (right) while playing Scooter Chase on test phase 1.

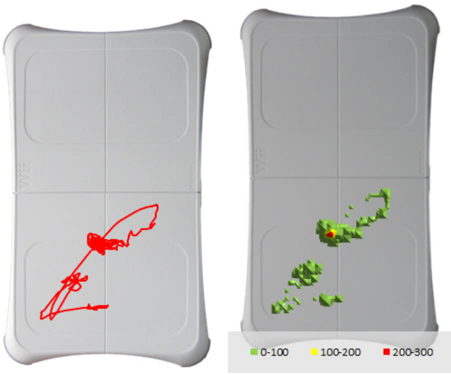

Figure A.5: Participant 5 COP's path (left) and frequency map (right) while playing Scooter Chase on test phase 1.

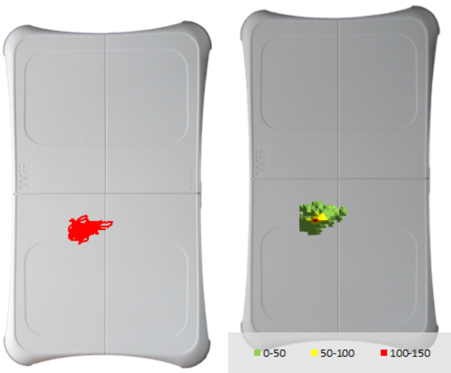

Figure A.6: Participant 6 COP's path (left) and frequency map (right) while playing Scooter Chase on test phase 1.

Test Phase 1 Balance Assessment Charts

Appendix B

Test Phase 2 Questionnaire and Explanation Required Topics

This appendix contains the tables that describe the questionnaire filled by participants of the second test phase, described on subchapter 5.2 and the topics chosen for the explanation level required evaluation of the same test.

Test Phase 2 Questionnaire and Explanation Required Topics

Table B.1: Questions and possible answers player to fill for test phase 2.

I practice physical exercise regularly.				
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

I enjoyed playing Scooter Chase.				
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

I enjoyed playing Segway Stroll.				
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

I would like to play these games regularly.				
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

I felt I was doing physical exercise/effort.				
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

These games motivate physical exercise practice.				
Strongly disagree	Disagree	Neutral	Agree	Strongly Agree

Device calibration was:				
Very hard	Hard	Normal	Easy	Very easy

Controlling the vehicles was:				
Very hard	Hard	Normal	Easy	Very easy

Objective fulfilment was:				
Very hard	Hard	Normal	Easy	Very easy

Table B.2: Explanation required analysis topics.

Scooter Chase			
#	Measured Topic	Scale	Explanation
T1	WBB postion	[1,5]	How the user understands the WBB placement.
T2	WBB calibration	[1,5]	How the user understands the WBB calibration process and then performs it.
T3	Smartphone calibration	[1,5]	How the user understands the smartphone calibration process and then performs it.
T4	How to move	[1,5]	How the user understands that is needed to perform a heel toe standing on top of the WBB in order to move.
T5	How to turn	[1,5]	How the user understands that rotating the smartphone will make the scooter to turn.
T6	Must catch the cat	[1,5]	How the user understands that the game's main goal it to catch the cat.
T6	Must avoid obstacles	[1,5]	How the user understands and avoids obstacles.
T8	How to locate the cat	[1,5]	How the user understands that the arrow point to the cat's direction.

Segway Stroll			
#	Measured Topic	Scale	Explanation
T9	WBB postion	[1,5]	How the user understands the WBB placement.
T10	WBB calibration	[1,5]	How the user understands the WBB calibration process and then performs it.
T11	How to move	[1,5]	How the user understands that is needed to perform a forward reach on top of the WBB in order to move.
T12	How to turn	[1,5]	How the user understands that exerting more presure on the sides will make the segway to turn.
T13	How to brake	[1,5]	How the user understands that is needed to perform a toe raise on top of the WBB in order to brake.
T14	Must pass the flags	[1,5]	How the user understands that he has to pass between flags to receive points.
T15	Must pass before timeout	[1,5]	How the user understands that he has to pass between flags before the timer runs out.
T16	Must avoid obstacles	[1,5]	How the user understands and avoids obstacles.
T17	Must avoid traps	[1,5]	How the user understands How the user understands and avoids traps.

Test Phase 2 Questionnaire and Explanation Required Topics

Appendix C

Test Phase 2 Balance Assessment in the Tandem Position Charts

In this appendix are presented the COP's path, amplitude and frequency maps obtained while the participants performed a tandem stance, while playing the exergames Scooter Chase.

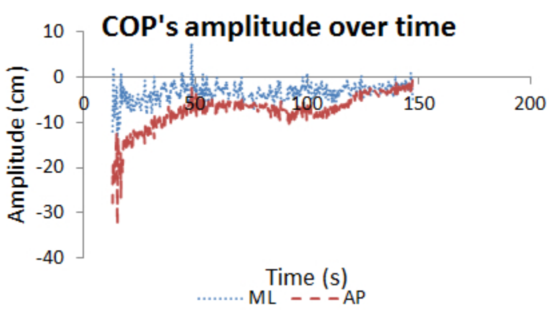

Figure C.1: Participant 1 COP's amplitude over time while playing Scooter Chase on test phase 2.

Test Phase 2 Balance Assessment in the Tandem Position Charts

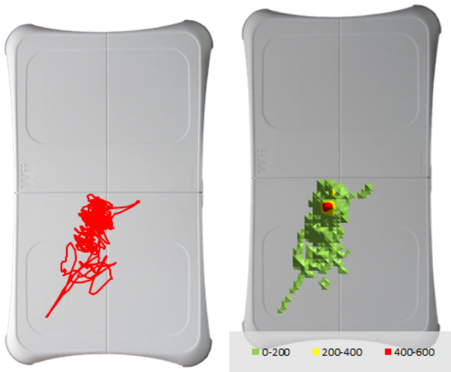

Figure C.2: Participant 1 COP's path (left) and frequency map (right) while playing Scooter Chase on test phase 2.

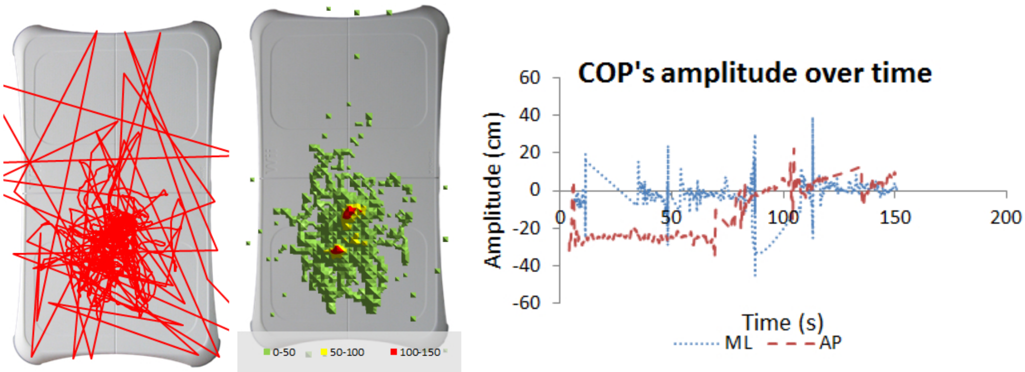

Figure C.3: Participant 2 COP's path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

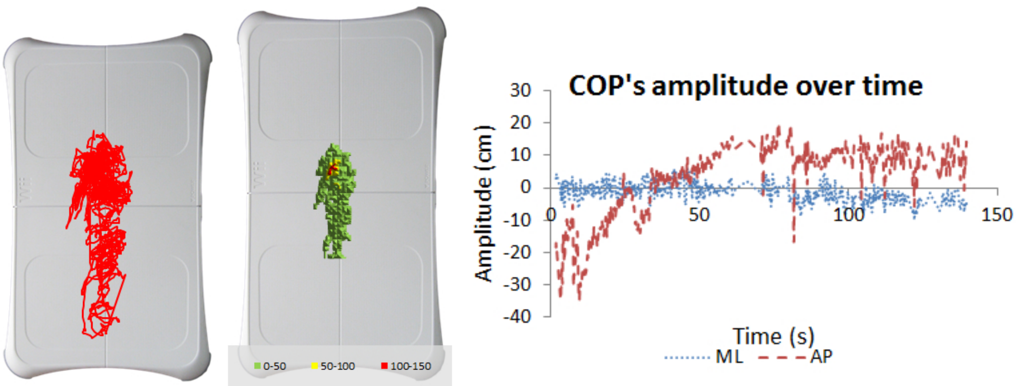

Figure C.4: Participant 3 COP's path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

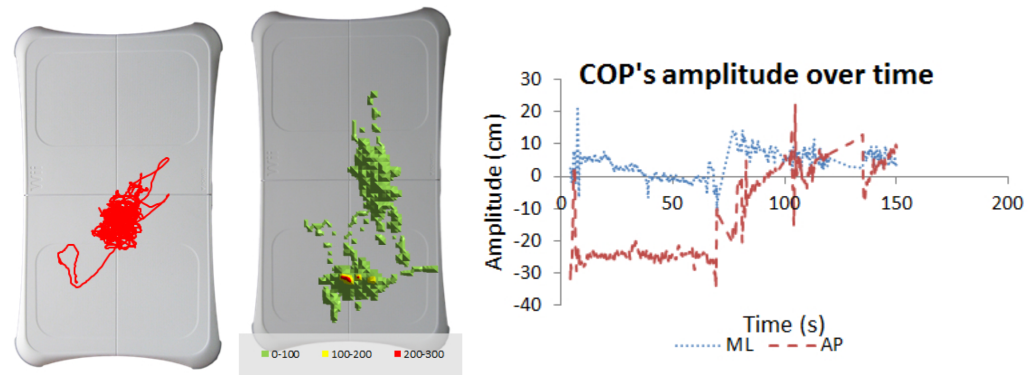

Figure C.5: Participant 4 COP's path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

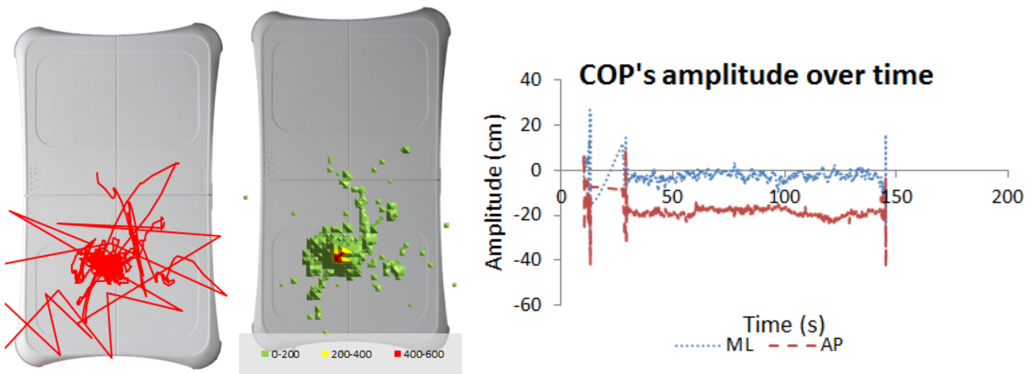

Figure C.6: Participant 5 COP's path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

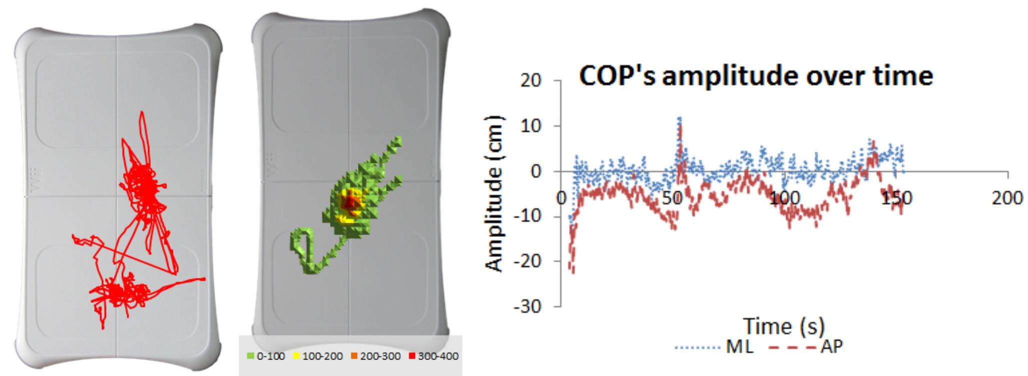

Figure C.7: Participant 6 COP's path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

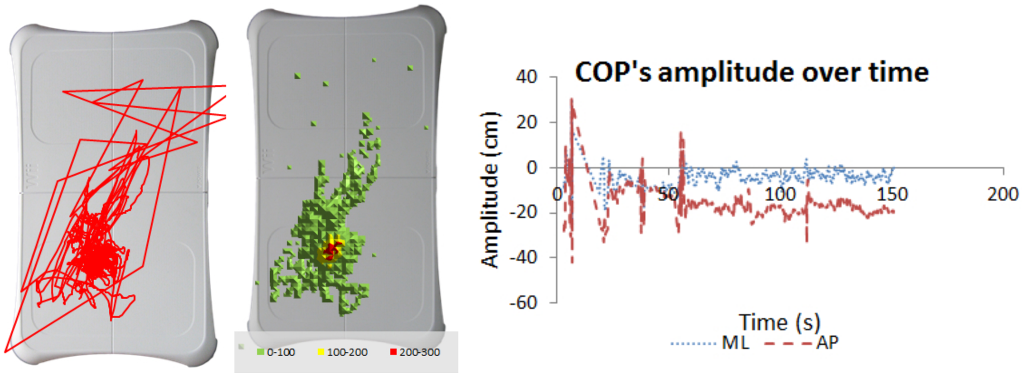

Figure C.8: Participant 7 COP’s path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

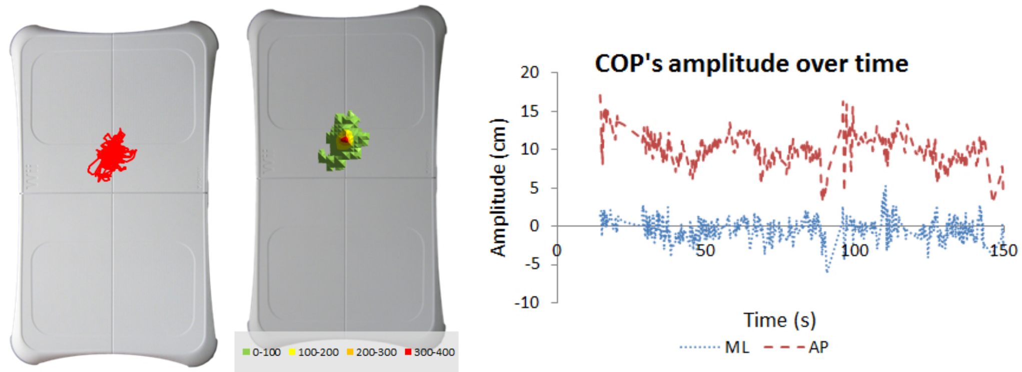

Figure C.9: Participant 8 COP’s path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

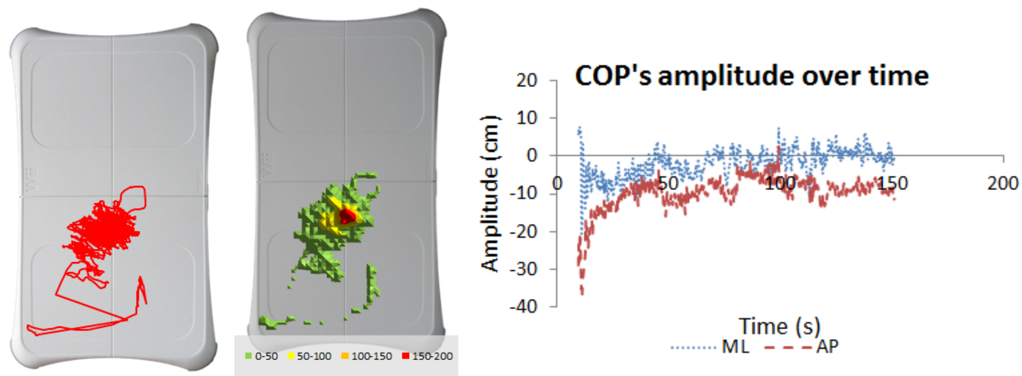

Figure C.10: Participant 9 COP’s path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

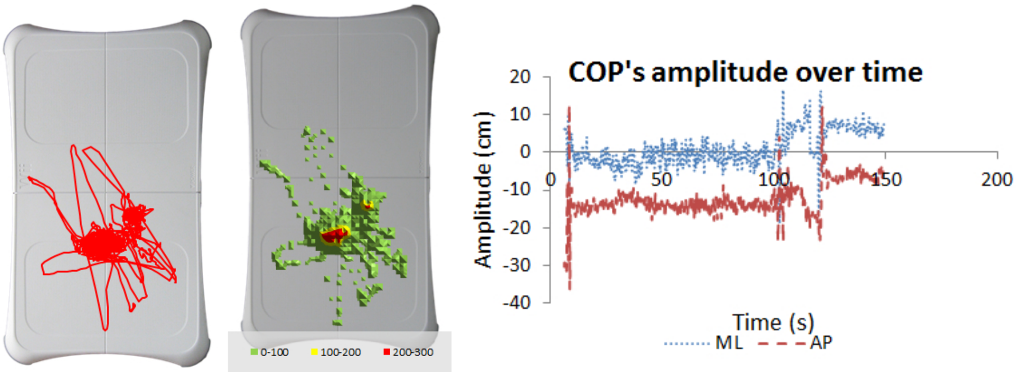

Figure C.11: Participant 10 COP's path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

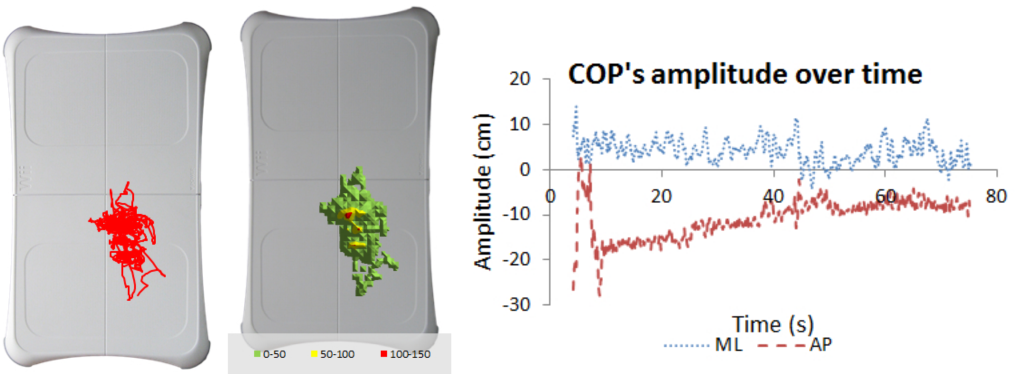

Figure C.12: Participant 11 COP's path (top-left), amplitude over time (down) and frequency map (top-right) while playing Scooter Chase on test phase 2.

Test Phase 2 Balance Assessment in the Tandem Position Charts

Appendix D

Test Phase 2 Balance Assessment in the Standing Position Charts

In this appendix are presented the COP's path, amplitude and frequency maps obtained while the participants performed a standing stance, while playing the exergames Segway Stroll.

Figure D.1: Participant 3 COP's path while playing Segway Stroll on test phase 2.

Test Phase 2 Balance Assessment in the Standing Position Charts

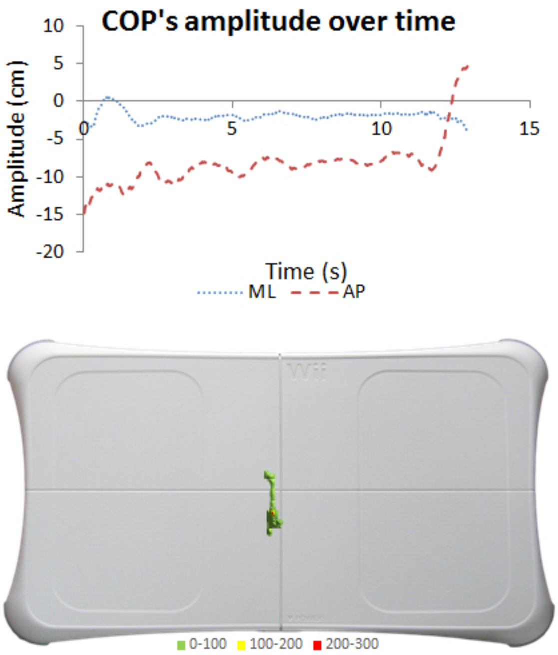

Figure D.2: Participant 3 amplitude over time (up) and frequency map (down) while playing Segway Stroll on test phase 2.

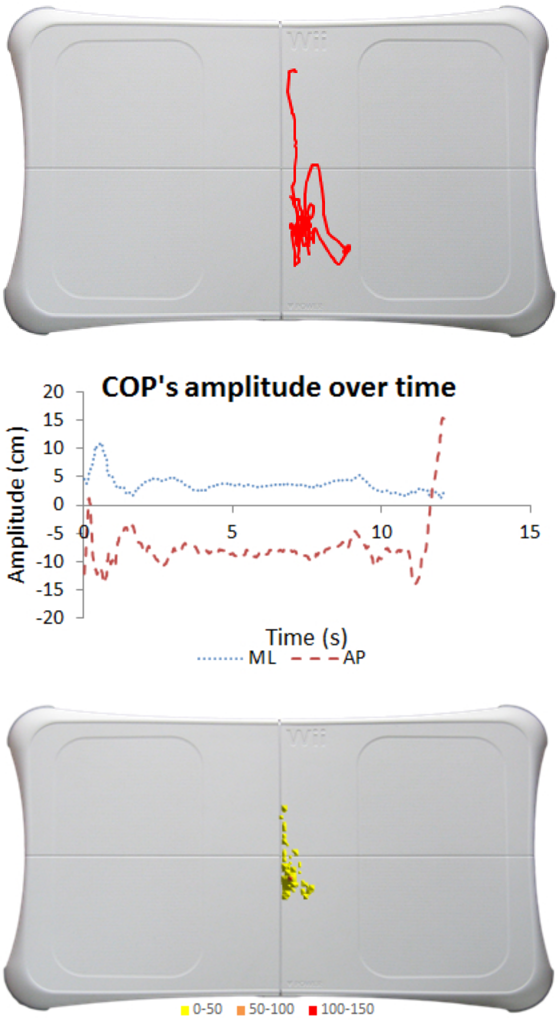

Figure D.3: Participant 5 COP's path (up), amplitude over time (middle) and frequency map (down) while playing Segway Stroll on test phase 2.

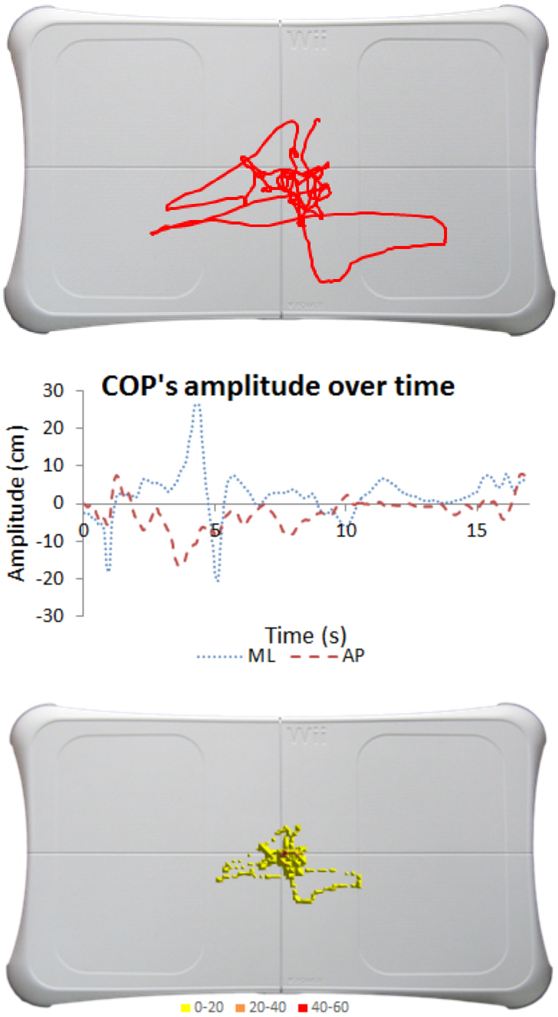

Figure D.4: Participant 6 COP's path (up), amplitude over time (middle) and frequency map (down) while playing Segway Stroll on test phase 2.

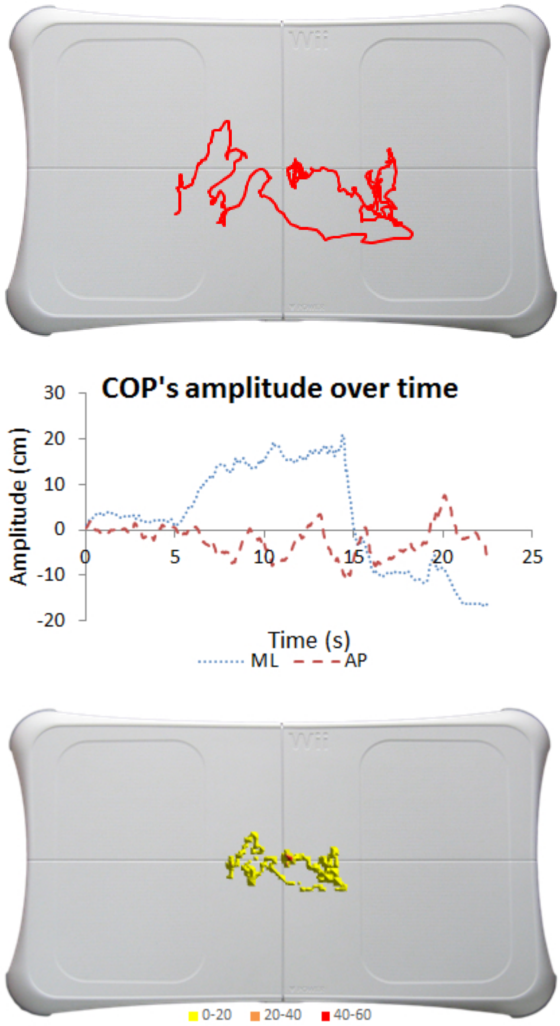

Figure D.5: Participant 8 COP's path (up), amplitude over time (middle) and frequency map (down) while playing Segway Stroll on test phase 2.

Test Phase 2 Balance Assessment in the Standing Position Charts

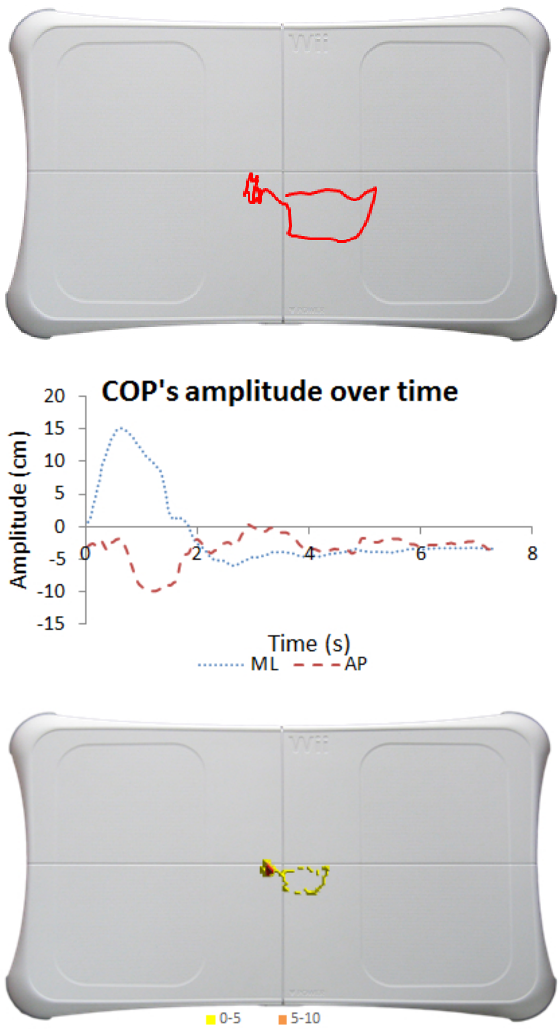

Figure D.6: Participant 10 COP's path (up), amplitude over time (middle) and frequency map (down) while playing Segway Stroll on test phase 2.