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Rehabilitation and Health Technologies

The feasibility of evaluating the effect of using Wii Fit balance games to train postural control in children with cerebral palsy

by

Afrah Almuwais

Thesis for the degree of Doctor of Philosophy

November 2015

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF HEALTH SCIENCES

Thesis for the degree of Doctor of Philosophy

THE FEASABILITY OF EVALUATING THE EFFECT OF USING WII FIT BALANCE GAMES TO TRAIN POSTURAL CONTROL IN CHILDREN WITH CEREBRAL PALSY

Afrah Khalaf Almuwais

The aim of this research is to investigate the usability and potential effect of Wii Fit games as postural control intervention and Wii Balance Board [WBB] as postural control assessment tool in clinical rehabilitation for children with cerebral palsy [CP]. Two studies were conducted to evaluate the intra- and inter-session reliability of the WBB in measuring Centre of Pressure [COP] path length of children with and without CP. 12 children {mean age 8.75 ± 1.7}, and 12 aged matched children with CP attended two sessions during one week. Participants were asked to stand on the WBB on both legs with eyes open [EO2L] and closed [EC2L], and to stand on one leg with eyes open [EO1L] and closed [EC1L]. The results showed excellent reliability of the WBB COP length during EO2L [ICC= 0.96] and EC2L [ICC= 0.95] and moderate reliability during EO1L [ICC=0.65] and EC1L [ICC= 0.794]. However, children with CP were only able to perform double-leg stance tasks; the WBB COP length achieved excellent reliability during EO2L [ICC=0.92] and moderate to poor reliability during EC2L [ICC=0.58]. The third study was conducted to test the methodological feasibility for conducting future randomised controlled trail [RCT] that will investigate the effect of the Wii Fit balance games training on standing postural control and functional balance in children with CP. 11 children with CP were asked to attend eight sessions for four weeks to play with Wii Fit balance games. Participants were assessed pre- and post- Wii Fit with Paediatric Balance Scale [PBS], Timed Up and Go [TUG] and WBB COP length. The results found no significant differences between pre and post Wii Fit for COP length [EO2L; p=0.21, EC2L; p=0.53], PBS [p=0.11] and TUG [p=0.35]. The Wii Fit balance games are feasible and enjoyable games for children with CP. However, a RCT with larger sample is required to provide evidence about its effectiveness with children with CP. The feasibility outcomes of this study are to inform future RCT.

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DECLARATION OF AUTHORSHIP

I, **Afrah Almuwais**

declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

The feasibility of evaluating the effect of using Wii Fit balance games to train postural control in children with cerebral palsy

I confirm that:

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3. Where I have consulted the published work of others, this is always clearly attributed;
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Date: **26th November 2015**

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Abbreviations

6MWT	**Six-minutes-walk test**
10MWT	**10 Meter Walk Test**
ABCS	**Activity Balance Confidence Scale**
ADL	**Activities of daily living**
ANOVA	**Analysis of variance**
AP	**Anterior-posterior**
APA	**Anticipatory postural adjustments**
AVN	**Acute vestibular neuritis**
BBS	**Berg Balance scale**
BMI	**Body mass index**
BOS	**Base of support**
BOT-2	**Bruininks–Oseretsky test of Motor Proficiency 2nd Edition**
BP	**Baropodometer platform**
CB&M	**Community Balance and Mobility Scale**
CI	**Confidence interval**
COB	**Centre of Balance**
COG	**Centre of gravity**
COM	**Centre of mass**
COP	**Centre of pressure**
CP	**Cerebral palsy**
DCD	**Development coordination disorder**
DS	**Down syndrome**
EMG	**Electromyography**
EO2L	**Stand on both legs with eyes open**
EC2L	**Stand on both legs with eyes closed**
EO1L	**Stand on one leg with eyes open**
EC1L	**Stand on one leg with eyes closed**
FESI	**Falls efficacy scale-International**
FIM	**Functional independence measure**
FRT	**Functional Reach Test**
GMFCS	**Gross Motor Function Classification System**
GMFM	**Gross motor functional measure**
ICC	**Interclass coefficient**
ICF	**International Classification of Functioning, Disability and Health**
ISVR	**Institute of Sound and Vibration Research**
KFMC	**King Fahad Medical City**
LED	**Infrared light-emitting diodes**
LEFS	**Lower Extremity Functional Scale**
LL	**Latero-lateral**
MABC-2	**Movement Assessment Battery for Children**
MACS	**Manual Ability Classification System**
MCID	**Minimal clinically important difference**
MDC	**Minimum detectable change**
ML	**Medial-lateral**

MoA	**Migraine without Aura**
NHS	**National Health Services**
NRES	**National Research Ethics Service**
PACES	**Physical activity enjoyment scale**
PBS	**Paediatric Balance Scale**
PD	**Parkinson's disease**
PEDI	**Paediatric Evaluation of Disability Index**
RCT	**Randomised control trial**
RMS	**Root mean square**
ROM	**Range of Motion**
RPA	**Reactive postural adjustments**
RRA	**Rose Road Association**
SBM	**Smart balance master**
SCSIT	**Southern California Sensory Integration Tests**
SD	**Standard deviation**
SEBT	**Star Excursion Balance Test**
SEM	**Standard errors of measurements**
SLST	**Single Leg Stance Test**
SOT	**Sensory Organisation Test**
STS	**Sit-To-Stand**
TBI	**Traumatic Brain injury**
TD children	**Typically developed children**
TMS	**Transcranial magnetic stimulation**
TTB	**Time to Boundary**
TUDS	**Timed Up and Down Stairs**
TUG	**Timed Up & Go test**
UVL	**Unilateral peripheral vestibular loss**
UPDRS	**Unified Parkinson's Disease Rating Scale**
vGRF	**Vertical component of the ground reaction force**
WBA	**Weight bearing asymmetry**
WBB	**Wii Balance Board**

Chapter 1: Introduction

The importance of conducting this research, what the research is about and how the research questions were formed, is presented in this chapter. A simple layout of the three main stages of the research is also given, including the research aims and objectives

1.1 Why did I conduct this research?

During my clinical experience as a paediatric physiotherapist, I worked with children with cerebral palsy [CP]. This was because of the high prevalence of CP in Saudi Arabia, and the lack of community services, at homes or schools, in the Saudi health system. The majority of children with CP in Saudi Arabia undertake their rehabilitation sessions at hospital clinics. Therefore, my main treatment goals were to improve children's independence, facilitate functional activities, encourage social interaction with the community and provide family-centred service where parents are partners in the care.

Tailoring a treatment plan to each patient's needs and preferences is important to achieve therapy goals. Making the treatment exercises more functional and practiced with everyday activities, improves the patient adherence to the treatment. In the case of children, the treatment needs to be creative to inspire them to perform the intended movement. When the child is motivated to exercise, the training adherence is much higher. Games are usually used in training children, as they can relate to and benefit from. When a child is involved in a game that captures his/her attention and the game challenges him/her to perform a certain movement, the therapy goals may be achieved less painfully. Therefore, selecting a game that a child enjoys and encourages a specific movement is crucial.

Nowadays, technology has become an essential part of our daily lives. Some of the available technology, such as video games, can be used in care delivery for children with CP. Using new videogames, such as Nintendo Wii, can be enjoyable and may improve their functional abilities. In addition, therapists will save time trying to design exercises that ensure that children have fun while exercising. Furthermore, these games can be played by more than one player; therefore, children can play them with their siblings or peers. However, such games have been launched only recently and new studies need to be conducted to investigate their effectiveness. Therefore, I was motivated to conduct research on the effectiveness of Wii games on functional balance improvements among children with CP.

1.2 What is the research about?

Impairments of the body structure and function, such as range of motion [ROM], strength and sensation, influence the postural control ability of children with CP. For example, children with CP have decreased ROM of hip extension and external rotation and ankle dorsiflexion (Lowes et al. 2004), which makes them adopt a crouched posture to respond to balance perturbations (Burtner et al. 1998) or prepare motor coordination for moving (Thorpe et al. 1998) like typically developed [TD] children. Additionally, children with CP have sensory impairments in proprioception sensation, demonstrated as decreased kinaesthesia and joint position sense (Wingert et al. 2009). These sensation impairments limit their ability to reproduce movements, regardless of their motor abilities, and contribute to balance impairments. Consequently, children with CP have an increased postural sway compared to TD children (Rose et al. 2002; Donker et al. 2008). The impaired balance experienced by CP children challenges their ability to adapt to threats to balance, which can make them feel unstable. therefore, they prefer sedentary activities with limited social interaction (Imms 2008).

The Nintendo Wii is an interactive virtual reality video game system introduced in the US and the UK at the end of 2006. One of the most popular games is Wii Fit, a compilation of fitness game with many different aerobic, strengthening, yoga and balance exercises. These games are usually played with the Wii balance board [WBB], because it requires players to shift their weight in different directions. The WBB is a communication tool, which transfers the data of the player's movement to the Wii console.

The weight shifting nature of the Nintendo Wii Fit balance games can be a task-specific training tool for balance rehabilitation. It was found that to facilitate the plasticity of neuromuscular systems, an adequate amount of task-specific training may lead to improvements in task practice (Hornby et al. 2011). When weight shifting practice is considered a task-specific practice, improvements in standing balance can be achieved (Hartveld & Hegarty 1996). Thus, many researchers hypothesised that the Wii Fit balance games are effective in improving balance among adults and children with balance impairments. Most studies found in the literature concluded that subjects who used the Wii Fit games showed significant improvements in static and dynamic balance abilities (Chapter 3). These studies were conducted with adults who have limited balance due to aging, musculoskeletal injuries, neurological deficits or vestibular loss. Only a limited number of studies have been conducted with children with poor balance due to different diagnoses, including CP. However, due to the small sample size in the studies conducted with children with CP, their results cannot be generalised. Additionally, none of these studies had a randomised control group to show the pure effect of the Wii Fit balance games on static and dynamic balance. To the author's knowledge, there has been no randomised control trial [RCT] study yet that has investigated the effect of Wii Fit games on both static and dynamic balance of children with CP.

In addition, the WBB as part of the Nintendo Wii Fit, is a weight sensor plate that communicates with the Wii console wirelessly about the player's weight distribution during game play. Therefore, some researchers investigated the ability of the WBB to provide data that can be used to calculate centre of pressure [COP] parameters to assess standing balance. Researchers who were interested in this area have concluded that the WBB provides valid and reliable COP parameters which are comparable to laboratory force plate (Chapter 3). However, the WBB was tested with adults, who may show different reliability values than children or patient populations. Therefore, the WBB needs to be tested for reliability with TD children to establish reliable reference data standing balance measurement for children. Then, the WBB can be used to assess balance for children with CP. To the author's knowledge, thus far, the reliability of the WBB data has not been tested for children with CP.

As the Wii Fit and WBB work together, I was interested in investigating the capability of including both of them in clinical rehabilitation for children with CP. Due to the gap in literature regarding using the Wii Fit games as a balance training rehabilitation tool for children with CP, an RCT is needed. Therefore, this study was designed to be a methodological feasibility study, which can inform about the suitability of the methods and procedures for a future RCT with a larger powered sample. In addition, this study will focus on using both the WBB as balance assessment tool and its reliability values when testing TD children and children with CP. The main purpose of the present study is to investigate the usability and potential effect of commercially available technology as postural control training and assessment tools in clinical settings.

1.3 Research questions

- How feasible it is to conduct a RCT to test the effect of Wii Fit balance games on the standing postural control and functional balance mobility among children with CP?
- Can the WBB provide reliable measures of standing balance in children with or without CP?

1.4 Research hypotheses

1- **H_0:** Children with CP **will show no balance improvments** highlighted in a decrease in the COP length during double stance, increase in the total score of the PBS, and decrease in the time to complete the TUG following four weeks of the Wii Fit balance games training intervention.

   H_1: Children with CP **will show balance improvments** highlighted in a decrease in the COP length during double stance, increase in the total score of the PBS, and decrease in the time to complete the TUG following four weeks of the Wii Fit balance games training intervention.

2- **H_0:** The WBB **will not provide** a reliable COP length measure of standing balance among children with or without CP.

   H_1: The WBB **will provide** a reliable COP length measure of standing balance among children with or without CP.

1.5 Research design

This research involved three stages (Figure 1.1). In the first stage, a developmental work was conducted to select the appropriate software to communicate with the WBB. In this stage, two software programs were evaluated by comparing the COP points detected and weights measured by the software to certified weights applied on specific points marked on a grid sheet. In the second stage, two studies were conducted to evaluate the intra- and inter-session reliability of the WBB and that of the selected software in measuring COP path length of TD children and children with CP during standing. In the third stage, training with Wii Fit balance games was conducted for children with CP and the effect of training was measured by calculating the WBB's COP path length with other functional measures of balance. In the last stage, the main feasibility study was conducted using a pre- and post-test design. This design was selected to give a preliminary results of the effect of the Wii-Fit games as an intervention for a small sample size of children with CP.

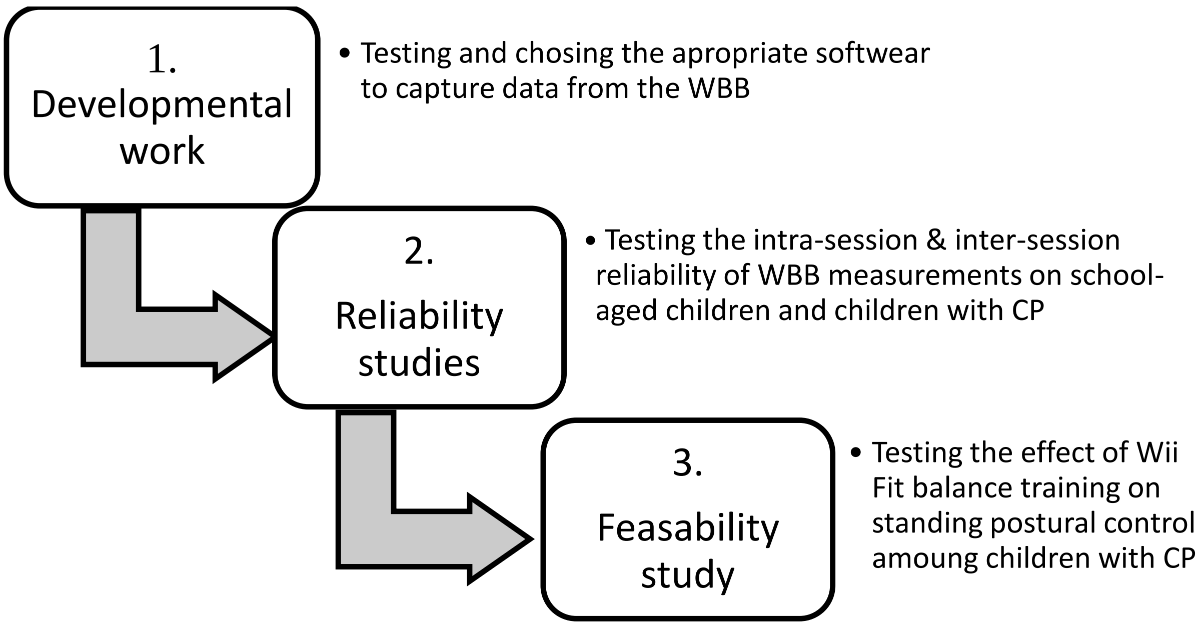


Figure 1.1: Diagram of the study's three stages

1.6 Research aims and objectives

In Stage 1 (Chapter 4), the aim was to determine the validity of the WBB data using different software after calibration. The objectives were;

- Select the appropriate software to communicate with the WBB.
- Identify the minimum weight that the WBB can read accurately.
- Find any systematic errors in testing that can be avoided or corrected.
- Design an algorithm to calculate COP length from the WBB's data

In Stage 2 (Chapters 5 and 6), the aim was to determine the intra-session and inter-session reliability of the WBB's data when measuring COP length among TD children and children with CP. The objectives were;

- Investigate within-day and between-day reliability of the COP length calculated from WBB with children with or without CP.
- Identify which balance task is more reliable and practical for children.

- Compare the results of COP length measured by the WBB between children with CP and TD children.

In Stage 3 (Chapter 7), the aim was to test the methodological feasibility for conducting future RCT which will investigate the effect of the Wii Fit balance games training on standing postural control and functional mobility in children with CP. The objectives were;

- Estimate recruitment rate to help in planning recruitment for the future RCT.
- Test the methodology in terms of the delivery of the Wii Fit games, including the duration and intensity of the Wii Fit training and the convenient research settings.
- Refine the selection of outcome measures for the ultimate RCT which will test the effectiveness of the Wii Fit balance games.
- Calculate sample size for a larger RCT based on the standard deviation of potential primary outcome measure.
- Record the adherence rate including frequency and duration of each game, and monitor adverse events.
- Gather feedback from children regarding their enjoyment level and the most games played to identify the most suitable games.
- Discuss the feasibility of implementing the Wii Fit games as a rehabilitation tool and the WBB as an assessment tool for children with CP in clinical and research settings.

This chapter gave an overview of what this research is about, the main research questions, the aims of each stage of the research and how the study was conducted. The following chapter will include background about main concepts on which the research questions are based, such as CP, postural control development in TD children and children with CP, postural control training and postural control assessment.

Chapter 2: Background

This chapter include some background on cerebral palsy, its aetiology, classification and the impairments that children with CP may have which challenge postural control during standing. Then, the postural control mechanism is introduced, including biomechanics of standing and postural control development in TD children and children with CP. Furthermore, the literature on postural control training is elucidated, including computerised balance training and virtual reality balance training for children with CP. It includes a section on postural control assessment, including COP parameters, their reliability, and what factors can influence their reliability. This section contains an explanation of how postural control can be assessed to address the effectiveness of rehabilitation interventions.

2.1 Cerebral palsy

CP is one of the most major neuromuscular impairments that affect children. One in every 400 children is affected by CP in the United Kingdom (Blair & Stanley 1997). CP is not a diagnosis but a group of disorders. This is because only limited information is available regarding its aetiology, pathology and prognosis. Owing to its complexity and variety of impairments, the definition of CP has been debated through the years. Rosenbaum et al. (2007, p.9) defined CP as 'a group of permanent disorders of the development of movement and posture, causing activity limitations that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication and behaviour, by epilepsy and by secondary musculoskeletal problems.'(Rosenbaum et al. 2007).

2.1.1 Aetiology and risk factors

Since CP is defined as a group of disorders that occur in the developing fetal or infant brain, the aetiology of CP is difficult to identify. This is because of the inability to identify the timing that the disorder occurs in the brain and the long time lag between the assumed time and CP recognition (Blair & Stanley 1997). Based on the cases studied in the literature, the aetiology of CP is associated with various risk factors. Although these risk factors cannot be classified as the causes of CP, they are aetiologically significant (Blair & Stanley 1997). The following risk factors have been identified:

2.1.1.1 Genetic Factors

Familial cerebral palsy can be a result of recessive genes. However, it is rarely found in Western countries, in contrast to other countries like Saudi Arabia where consanguineous marriages are culturally acceptable (Al-Rajeh et al. 1991).

2.1.1.2 Pregnancy Factors

It is believed that birth-weight ratio is inversely associated with the risk of CP. This risk increases with multiple births because they combine two factors: premature delivery and low birth-weight ratios (Blair & Stanley 1997). A high rate of toxaemia of pregnancy has been observed in the births of CP children compared to the total population of births, which is considered another risk factor (Blair & Stanley 1997).

2.1.1.3 Intrapartum Factors

Intrapartum factors produce hypoxia, which may occur due to the malpractice of obstetric intervention. Birth asphyxia is an exposure-response-outcome sequence initiated by hypoxia, which can result from inadequate supply of oxygen immediately prior to, during or just after delivery. Birth asphyxia accounts for 10% of CP in developed countries and over 24% in developing countries (Blair & Stanley 1997).

2.1.1.4 Post-Neonatal Factors

Post-neonatal aetiology can be acquired up to the age of 5 years. In developed countries, post-neonatal factors, such as motor vehicle accidents, non-accidental injury and post-operative causes account for 8% to 18% of CP cases. In developing countries, the percentage may be higher and causes are infective, anoxic or traumatic, with the majority being septicaemia and meningitis (Blair & Stanley 1997).

2.1.2 Classification

Clinicians and researchers have long debated how CP should be defined and what causes CP. This conflict extends to how children with CP should be classified. Traditionally, children were classified on the basis of clinical descriptions. However, recently, clinicians and therapists have agreed to use a new, valid and reliable means of classification.

The traditional descriptive classification system of CP was based on the ‘type’ of motor impairment, ‘topography’ of which parts of the body were affected and the severity of the motor impairments (Blair & Stanley 1985). Muscle tone characteristics, such as spastic, dyskinetic, hypotonic or ataxic, are the main types of motor impairment that have been used to classify CP. The most common type of motor impairment among CP is spasticity. It is characterised by an abnormal increase in muscle tone, which limits the control over voluntary limb movement. Spasticity is recognised with the presence of abnormal resistance to passive stretch, called a clasp knife effect, hyper-reflex and clonus (Blair & Stanley 1997). Dyskinesia occurs in conjunction with spasticity and is characterised by the presence of involuntary limb movements in the form of writhing movements 'athetoid', rigid posturing 'dystonic' or rapid, jerky movements 'chorea'. Hypotonia, which is a decrease in muscle tone, is rarely described as a primary movement disorder. This is because it is frequently accompanied by intellectual impairment (Blair & Stanley 1997). Ataxia is the fluctuation of muscle tone, causing the inability to control voluntary movement, which presents in the form of tremors. The distribution of motor impairments is what is called the 'topography', which is the second descriptive classification of CP. This topography varies among one limb 'monoplegia', two limbs 'diplegia' {where legs are affected more than the arms}, 'hemiplegia' {where the leg and arm of one side are more affected than the other side}, or four limbs 'quadriplegia' {where both arms and legs are affected equally}(Blair & Stanley 1997). Moreover, CP is further classified on the basis of the severity of motor impairments as severe, moderate or mild (Blair & Stanley 1985).

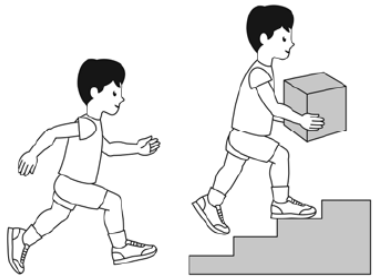
Although these classifications are descriptive, they are not reliable. This is because they are not operationally defined. For example, the term 'spastic diplegia' has variable and imprecise definitions. Some use it to describe children with CP who are spastic only in the legs, while others use it to describe children who are spastic in the arms. Although both these sets of children are categorized as children with spastic diplegia, they can perform very different functions. Therefore, traditional descriptive classification is not recommended for assessing children with CP because it is unreliable and may not be suitable to measure the progress of functional performance.

The International Classification of Functioning, Disability and Health [ICF] is the World Health Organization's conceptual framework, which is used for classification of health and health-related domains (WHO 2001). The ICF model covers three main domains; biological 'impairments', functional 'activity limitations' and social involvement 'participation restrictions' (Gorter et al. 2004). This model provides a useful way of classifying health disorders and designing proper treatment interventions and outcome measures.

The Gross Motor Function Classification System [GMFCS] was designed on the basis of the ICF model for CP children aged between 2 and 18 years old (Palisano et al. 1997; Palisano et al. 2006). It is a five-level classification system (Figure 2.1) used mainly by therapists for assessment, measurement and prognosis. It classifies CP children on the basis of their self-initiated movements, functional limitations and need for assistive devices, such as walkers, crutches and canes or wheelchairs (Palisano et al. 1997). The GMFCS is a reliable and discriminative system, which demonstrates validity and clinical utility. It is a standardized international system and has been translated into approximately 22 different languages. It was initially developed for CP children aged between 2 and 12 years old (Palisano et al. 1997); however, subsequently, it was expanded and revised to include adolescents aged between 12 and 18 years old (Palisano et al. 2006).

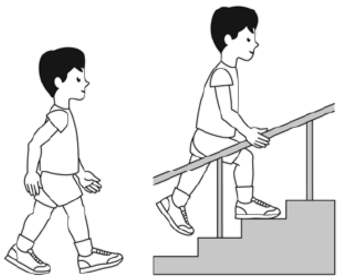
The GMFCS combines the clinical description of the impairments, including limb distribution and type of motor impairment, with functional limitations and participation restrictions. It provides a clinical picture with the level of severity and reliable prognostic information of motor abilities. There is a statistically significant association between the impairments classification by clinical descriptions and the functional classification by GMFCS (Gorter et al. 2004). According to Gorter et al. (2004), 87.8% of children with hemiplegia were classified as GMFCS level I and 7.1% were classified as level II. Of the children classified as GMFCS level I, 36.9% had diplegia, whereas 3.4% had quadriplegia (Gorter et al. 2004). This shows that children with hemiplegia or diplegia tend to be more functional than children with quadriplegia, who are most represented at GMFCS level V. This shows the importance of functional classification besides the impairment classification and how children with the same impairment category may function differently.

GMFCS E & R Descriptors and Illustrations for Children between their 6th and 12th birthday



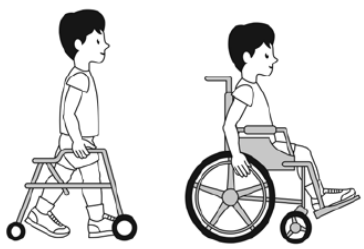
GMFCS Level I

Children walk at home, school, outdoors and in the community. They can climb stairs without the use of a railing. Children perform gross motor skills such as running and jumping, but speed, balance and coordination are limited



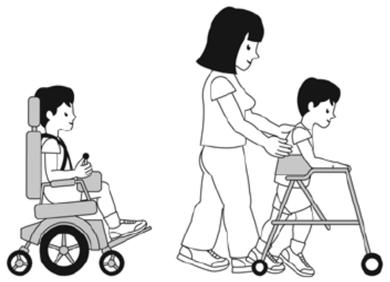
GMFCS Level II

Children walk in most settings and climb stairs holding onto a railing. They may experience difficulty walking long distances and balancing on uneven terrain, inclines, in crowded areas or confined spaces. Children may walk with physical assistance, a hand-held mobility device or used wheeled mobility over long distances. Children have only minimal ability to perform gross motor skills such as running and jumping.



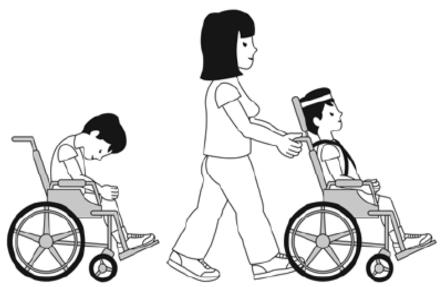
GMFCS Level III

Children walk using a hand-held mobility device in most indoor settings. They may climb stairs holding onto a railing with supervision or assistance. Children use wheeled mobility when traveling long distances and may self-propel for shorter distances.



GMFCS Level IV

Children use methods of mobility that require physical assistance or powered mobility in most settings. They may walk for short distances at home with physical assistance or use powered mobility or a body support walker when positioned. At school, outdoors and in the community children are transported in a manual wheelchair or use powered mobility.



GMFCS Level V

Children are transported in a manual wheelchair in all settings. Children are limited in their ability to maintain antigravity head and trunk postures and control leg and arm movements.

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CanChild: www.canchild.ca

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The Royal Children's Hospital, Melbourne

Figure 2.1: The GMFCS five levels (Palisano et al. 1997)

2.1.3 Impairments affecting postural control in children with CP

Children with CP across the GMFCS levels experience a wide range of impairments of the body structure and function. These impairments include strength, muscle activation pattern, ROM and sensation. This section only includes the impairments of children with CP classified at GMFCS levels I-III, which affect standing postural control.

2.1.3.1 Muscle strength

Decreased muscle strength is exhibited by children with CP in ankle dorsi-flexors, plantar flexors, knee flexors and extensors and hip abductors and adductors (Lowes et al. 2004; Eek & Beckung 2008). This impaired force production is owing to increased muscle stiffness and limited ROM, which alter the muscle tension curves (Lowes et al. 2004). Thus, it affects the ability to coordinate muscle timing and force production to balance threats (Burtner et al. 1998; Thorpe et al. 1998; Lowes et al. 2004). Strength training for ankle and hip muscles may increase ROM and force production, where ankle or hip strategies can be performed during postural control (Lowes et al. 2004). Muscle strength in children with CP is highly associated gross motor function (Ross & Engsberg 2007) and walking ability (Eek & Beckung 2008), as classified in the GMFCS. This shows that muscle strength is essential for standing postural control and weight shifting control during walking.

2.1.3.2 Muscle activation

Although muscle weakness was detected in children in CP, the onset and pattern of muscle activation during postural adjustments were compared between TD children and children with CP. It was observed that children with CP, who had more walking experience, demonstrate proximal to distal recruitment of the agonist leg muscles, gastrocnemius and hamstring; however, no significant difference was found in onset latencies of these muscles when compared to TD children with the same walking experience (Nashner et al. 1983; Burtner et al. 1998). Furthermore, a coactivation of the agonist and antagonist muscles was demonstrated by children with CP with a decrease in trunk muscle activation (Burtner et al. 1998). This coactivation may be employed to stabilize the joints during stance and to compensate the decreased activation of trunk muscles to increase postural control.

2.1.3.3 Range of Motion

Children with CP have decreased ROM of hip extension and external rotation, and ankle dorsiflexion narrows the base of support, which challenges postural control ability (Lowes et al. 2004). Owing to the limited ROM of the lower extremity, children with CP tend to adopt a crouched posture. This causes poor biomechanical alignment, thereby affecting their ability to generate effective muscular contractions. Interestingly, when TD children are standing in a crouched stance posture, their muscle onset latencies are more constrained, their muscle organization changes from a proximal to distal organization pattern, and the coactivation of synergistic muscles increases (Weck et al. 1994; Sienko-Thomas et al. 1995; Burtner et al. 1998). Significant differences are noticed in muscle activation when comparing TD children with children with CP during their upright stance; however, this difference becomes insignificant when TD children stand in a crouched posture (Burtner et al. 1998). This emphasizes the importance of mechanical contributions to postural control regardless of neural pathology.

2.1.3.4 Sensation

The somatosensory system, which includes proprioception and tactile sensations, is one of the three main systems used to maintain balance. Tactile sensation is the ability to localize and characterize objects with touch. Children with CP exhibit tactile roughness and tactile object recognition deficits of the upper extremities (Wingert et al. 2008). Proprioception is a modality that employs inputs from muscle, joints and fibres. It comprises the sense of limb movement ‘kinaesthesia’ and the sense of static joint position (Gandevia et al. 2002). Impairments in proprioception make children with CP rely heavily on visual input to maintain balance (Liao et al. 2001). Decreases in kinaesthesia and joint position sense are observed among children with CP (Wingert et al. 2009). Abnormal biomechanical alignment, muscle weakness and increased muscle tone in children with CP may contribute to providing inaccurate sensations of positions or joints, leading to conflicting sensory input (Wingert et al. 2009). These sensation impairments contribute to balance perturbations in children with CP or limit their ability to maintain balance.

In summary, postural control during standing in children with CP is challenged by these impairments, leading to abnormal balance reactions or mechanisms of stability. Therefore, it is important to understand postural control mechanisms and its development in TD children in order to clinically address the postural control mechanisms of children with CP.

2.2 Postural control

2.2.1 Biomechanics of standing postural control

Winter (1995, p.194) defined centre of mass [COM] as ‘the point equivalent of the total body mass in the global reference system and is the weighted average of the COM of each body segment in 3D space' (Winter 1995). The COM of the human body normally lies at the level of the second sacral vertebrae (Norkin & Levangie 1992). The centre of gravity [COG] is the vertical projection line of the COM (Winter 1995), which should fall within an individual's base of support [BOS] to maintain balance. Therefore, COM and COG are equally presented and researchers usually use these terms synonymously. However, COP is different from COM and COG.

The COP is a point location of the vertical ground reaction force vector. It is calculated as a weighted average of all pressures within the surface area in contact with the ground (Winter 1995). When an individual stands on one leg, COP lies within the foot of that leg. On the other hand, when an individual stands on both legs, COP lies between the two feet depending on the weight distribution (Winter 1995). Pedersen et al. (2006) present a figure that illustrates the differences among COM, COG and COP while standing (Figure 2.2).

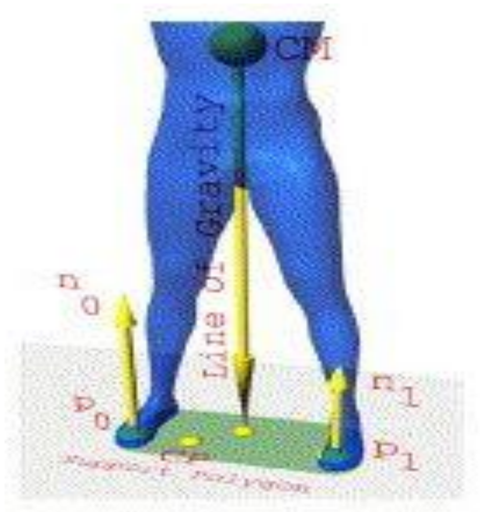


Figure 2.2: Biomechanics of standing

COM is represented by the arrow pointing towards the floor [labelled in the figure as CM], which is known as the line of gravity, as it points towards the COG. The point marked on the ground, close to the man's left foot, represents the COP [labelled here as CP]. The arrows pointing up from each foot represent the weight distribution, and the green area represents the base of support. (Pedersen et al. 2006)

The terms COG and COP are often used interchangeably. Therefore, the relationship between these two measures needs to be clearly defined to identify the differences between them during bilateral standing (Winter 1995). Winter (1995) introduced an inverted pendulum model of balance in the anterior-posterior [AP] direction (Figure 2.3). Figure 2.3 illustrates that COP and COG are inversely proportional, because when COG moves anteriorly, COP moves posteriorly to control the COG positioning during stance. This sequence shows that ankle plantar flexors and dorsiflexors control the body's COG. Figure 2.3 also demonstrates that the movement of COP is greater than that of COG to ensure the maintenance of equilibrium. Therefore, a deviation of a few centimetres of the COG within the toes may not be corrected by the extreme movement of COP, where stepping may be necessary to prevent falling (Winter 1995).

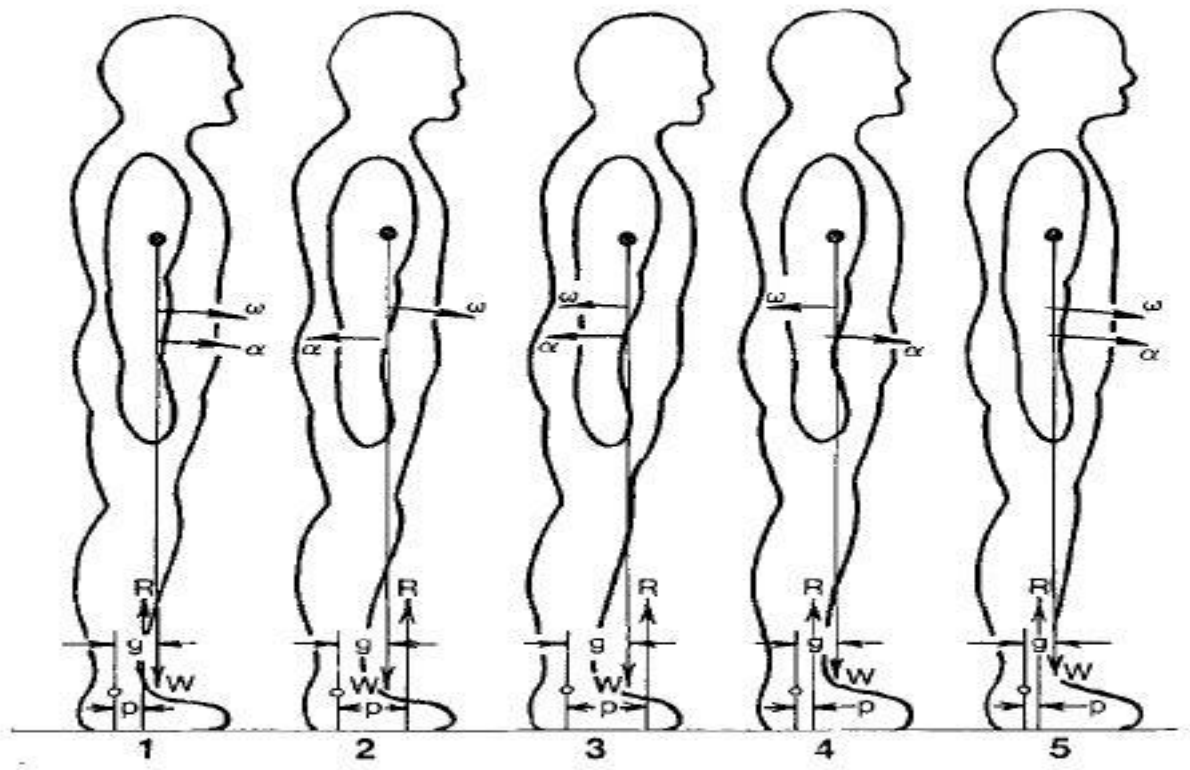


Figure 2.3: The relationship between COG and COP during AP sway

Anterior-posterior sway of a subject standing quietly on a force platform during five different points in time, showing the COG as [g] and the COP as [p] locations from the ankle joint along with the associated angular accelerations [a] and angular velocities [w]. (Winter 1995)

2.2.2 Postural control development in typically developed children

Balance in the form of stability is the ability to control COM within BOS, which is called postural control (Horak 1992). Balance can be static by controlling COM movement in the rest position or dynamic by controlling COM movement while performing a purposeful movement within the BOS. Understanding the development of balance in children is important to clinically address the balance impairments of children with CP. The balance development of healthy adults and children has been studied in literature in relation to the development of the sensory systems and the development of postural adjustments.

2.2.2.1 Sensory systems

Standing postural control is primarily regulated by the sensory system. The sensory system includes the visual, somatosensory and vestibular systems, which are integrated to provide information about the body and the environment with respect to gravity and motion, thereby assisting in the maintenance of postural control. This mechanism is seen in adults; however, children use these sensory systems differently when maintaining their balance, because each of these systems mature at a different rate (Westcott & Burtner 2004). Therefore, it is important to discuss the development of standing balance in children from the perspective of the three sensory systems.

The visual system combined with the somatosensory system is the dominant system for balance in early walkers (Sundermier & Woollacott 1998) and for children under three years(Shumway-Cook & Woollacott 1985b; Foudriat et al. 1993). Although children are mostly dependent on visual information to maintain balance, the visual system is still developing at this stage. Visual system maturation initially occurs between the ages of 5 to 6 years and subsequently between 11 to 13 years (Hirabayashi & Iwasaki 1995). Some recent studies state that children aged between 11 to 14 years have adult-like visual system (Peterson et al. 2006; Ferber-Viart et al. 2007), whereas other studies indicate that the visual system is fully developed in children between 14 to 16 years old (Hirabayashi & Iwasaki 1995; Steindl et al. 2006; Cumberworth et al. 2007).

For children of 3 years of age, the somatosensory system is the primary system of balance, with input from the vestibular system (Foudriat et al. 1993). The somatosensory system is most mature and adult-like when a child is aged between 3 to 4 years (Woollacott et al. 1987; Hirabayashi & Iwasaki 1995; Steindl et al. 2006; Cumberworth et al. 2007). The somatosensory system is the primary system for maintaining balance in children aged six years or older (Rine et al. 1998).

The vestibular system have the slowest maturation process among the other sensory systems. It works in conjunction with the visual system in children under 3 years old (Shumway-Cook & Woollacott 1985b; Foudriat et al. 1993) and with the somatosensory system in children aged over 3 years (Foudriat et al. 1993). The vestibular system could be damaged by middle ear effusion, a condition that commonly affects children (Casselbrant et al. 2000). In children aged between 7 to 10 years, the vestibular system is still developing and has not yet achieved an adult-like pattern (Rine et al. 1998; Cherng et al. 2001; Nolan et al. 2005; Steindl et al. 2006); therefore, children at this age cannot rely solely on vestibular input to maintain balance (Woollacott & Shumway-Cook 1990). The vestibular system in children has another period of development between the ages of 12 and 14 years (Steindl et al. 2006; Ferber-Viart et al. 2007). One study found that the vestibular system is adult-like in terms of standing, based on the postural sway area, in children aged 12 years (Peterson et al. 2006). In contrast, other studies have shown that the vestibular system continues to develop until the ages of 14 to 16 years (Hirabayashi & Iwasaki 1995; Cherng et al. 2001; Cumberworth et al. 2007).

The three sensory systems are integrated to provide information processed by the brain to inform the body to react with the environment with respect to gravity and motion. This sensory integration process directs the motor balance reactions of postural adjustments to maintain postural control (Ayres 1972). The ability to manage conflicting sensory information during balance activities improves with age (Peterson et al. 2006). The maturation of sensory systems is placed at the age of approximately 15 years (Steindl et al. 2006). However, children between the ages of 3 to 6 years have demonstrated the ability to perform balance activities (Foudriat et al. 1993; Steindl et al. 2006). Although sensory systems develop at different rates in children, the sensory integration process develops with training because it is a neuromotor learning process (Ayres 1972). Children were able to response to altered sensory information similar to that of adults by the ages 7 to 10 years (Shumway-Cook & Woollacott 1985a).

2.2.2.2 Postural adjustments

Postural control adjustments are made according to the changes in COM and BOS, which can be performed by two mechanisms: reactive postural adjustments [RPA] and anticipatory postural adjustments [APA]. RPA are adjustments that are made in reaction to an unexpected external shift in the COM outside the BOS. APA are adjustments that are made for anticipating internal postural controlling of the COM within the BOS, related to the production of voluntary movements, such as reaching forward while standing (Westcott & Burtner 2004).

The sensory, motor and musculoskeletal systems coordinate with each other to produce effective postural control mechanisms (Bernshteĭn 1967; Horak 1992). As stated above, the sensory system comprises the visual, vestibular and somatosensory systems. Output from these systems gives feedback to the individual for making postural adjustments. The motor system processes the neuromuscular response synergies and organises the appropriate activation of the muscles. The musculoskeletal system includes muscle strength, range of motion and biomechanical posture. Therefore, the musculoskeletal system provides the framework to move and produce postural muscle activity (Shumway-Cook & Woollacott 2001). Therefore, postural control development is based on the development of the sensory, motor and musculoskeletal systems, although these systems develop in a non-linear pattern at different rates (Westcott & Burtner 2004).

The development of RPA appears to be innate in the patterns of muscle coordination that are organised for head control, sitting balance and standing balance. There are periods in RPA development when some children demonstrate immature muscle co-contraction patterns, however, adaptable RPA can be achieved with experience and practice (Westcott & Burtner 2004). RPA develops in the stance of infants aged between 7 and 8 months, a time when they begin to demonstrate ankle strategies (Sveistrup & Woollacott 1996). RPA continues to follow a distal to proximal pattern of muscle coordination until the ages of 4 to 6 years (Forssberg & Nashner 1982). When a child is aged between 4 to 6 years, there is a disorganisation of RPA development in the standing postural muscle co-ordination patterns. However, it returns to adult-like patterns and matures gradually between the ages of 7 to 10 old (Forssberg & Nashner 1982).

Development of APA is related to patterns of motor coordination and is more dependent on practice and learning through experience, which makes APA appropriate for task-specific movement patterns (Vereijken et al. 1992). APA in standing begins to develop in infants as early as 10 months, and it becomes more consistent with increasing walking practice (Assaiante et al. 2005). APA is well developed by the time infants are 16 to 17 months (Witherington et al. 2002) and becomes adult-like by the age of 7 years (Girolami et al. 2010).

2.2.3 Postural control in children with CP

2.2.3.1 Sensory systems

Only limited research has been conducted on the milestones or maturation of sensory systems in children with CP; however, some research has explored the impairments of these systems. Children with or without CP, at the age of three years, depend on visual input while balancing in standing position. However, children with CP do not process this visual input in the same manner as children without CP (Woollacott & Burtner 1992). This dependence on vision decreases in children with CP between the ages of 7 to 9 years (Woollacott & Burtner 1992).

In children with CP, the somatosensory system performs poorly when they attempt to perform balancing tasks (Nashner et al. 1983; Shumway-Cook & Woollacott 1985a). When a child with CP stands on an unsteady surface, the sensory input is unreliable (Liao et al. 1997). However, when a child with CP who is aged between 6 to 7 years stands on a stable surface, the sensory input will be reliable and their performance may be similar to that of TD children (Cherng et al. 1999). Although children with CP rely heavily on the somatosensory system, they have difficulties in switching between systems when the sensory input is unreliable (Cherng et al. 1999).

In TD children, the vestibular system takes longer time to mature. Although only limited research has been conducted on the development of the vestibular system in children with CP, its development in such children may be slower than in children without CP. In addition, children with CP have minimal responses to vestibular input (Takiguchi et al. 1991) and have difficulties in processing vestibular information (Cherng et al. 1999). Therefore, in contrast to TD children, children with CP do not consider the vestibular system as a reference system to maintain balance.

Sensory integration dysfunction is one of the most important problems seen in children with CP. Besides impairments of the visual, vestibular and somatosensory systems, children with CP struggle with conflicting sensory information to obtain postural control. Therefore, children with CP experience some sensory perceptual problems, such as impairment of body image, right-left discrimination, position in space and visual perception problems and apraxia (Goldcamp 1984). In general, children with CP react to conflicting sensory information while performing balance activities in the same manner as TD children under the age of 7 years (Nashner et al. 1983). Children with CP vary on the basis of the affected body part, severity or functional level, their balance ability may also vary based on which system is most impaired. For example, CP children with spastic hemiplegia struggle with muscle activation coordination, CP children with ataxia have difficulty processing conflicting sensory information and CP children with diplegia face difficulty with both motor and sensory systems (Nashner 1985).

2.2.3.2 Postural adjustments

2.2.3.2.1 Reactive postural adjustments

Studies were found in literature that have tested the RPA in children with CP in standing positions (Nashner et al. 1983; Burtner et al. 1998; Ferdjallah et al. 2002; Chen & Woollacott 2007). Motor, musculoskeletal and sensory differences, which affect RPA, were investigated by comparing CP children to TD children.

Motor differences have been noticed in CP children with spastic hemiplegia who demonstrate poor timing and longer onset latency of muscle activation with proximal to distal, hips to ankle, patterns (Nashner et al. 1983). Children with CP and spastic diplegia have shown prolonged durations of muscle activation without clear onsets and offsets. Moreover, non-selective activation of agonist and antagonist muscles and a decreased activation of trunk muscles were identified when children underwent tests that examined crouched standing with platform perturbations (Burtner et al. 1998). When children with CP were tested for balance perturbation, they were able to tolerate fewer perturbations than TD children (Chen & Woollacott 2007). A child with CP between the ages of 8 to 13 years may respond to perturbation with similar control as that of a TD child between the ages of 4 to 8 years (Chen & Woollacott 2007). This shows that the RPA in children with CP are more delayed and impaired than normal children.

In terms of musculoskeletal differences, children with spastic diplegia tend to adopt a crouched position, which limits muscle recruitment during balance perturbation in stance (Burtner et al. 1998). The strategies of balance of children with CP have been analysed using COP measures. The transverse body rotation strategy was observed in children with CP to control anterior-posterior sway, which is effective when the ankle control is poor. Furthermore, limb protraction/retraction strategies were observed to control medial-lateral [ML] sway in CP children. As compared to TD children, children with CP demonstrate a greater COP path length, mean radial displacement and slower frequencies of sway (Ferdjallah et al. 2002; Rose et al. 2002).

2.2.3.2.2 Anticipatory postural adjustments

APA were tested in CP children while they were standing and reaching forward (Thorpe et al. 1998; Westcott et al. 1998a; Zaino 1999; Liu et al. 2000). On observing children with CP and TD children during a stand and reach task, differences were found in postural motor coordination patterns, postural muscle activation onsets and COP excursion.

Children with CP classified as level I on the GMFCS showed no differences in postural motor coordination patterns compared to TD children (Westcott et al. 1998a). However, CP children at level II showed slower onset times and larger time gaps between the onset of APA and the onset of reach based on the electromyogram [EMG] readings (Liu et al. 2000). The children at GMFCS level III, compared to children at GMFCS level I, showed the earliest activation of anticipatory postural muscle contractions (Westcott et al. 1998a). Furthermore, children with CP first showed a greater onset of distal posterior muscle, whereas TD children first showed greater onset of anterior distal muscles (Zaino 1999). While reaching forward, children with CP appear to move their COP, with increased COP path length, in ML direction rather than in an AP direction (Zaino 1999; Liu et al. 2000). Children with CP reach forward, while standing, more slowly and in a more variable pattern than TD children (Zaino 1999; Liu et al. 2000). However, when TD children were asked to stand in a crouched position and reach forward, their motor coordination pattern was similar to that of children with CP, who usually adapt their posture(Thorpe et al. 1998). Therefore, this musculoskeletal difference leads to an altered biomechanical posture, which affects APA while reaching forward.

In summary, the process of balance development in TD children was used as a reference to address the abnormal development of postural control in children with CP. This also provides an insight into the difficulties that children with CP face when maintaining balance. In addition, postural control impairments in children with CP can be used by therapists to plan for the proper rehabilitation program including possible effective treatments.

2.3 Postural control training

2.3.1 Computerised balance training

The impaired balance experienced by children with CP challenges their ability to adapt to threats to balance, making them feel unstable. Balance training is part of the physiotherapy treatment plan for a child with CP. Traditional balance training activities include weight shifting by the patient ,actively or passively, therapist applying perturbation to the patient's balance and patient performing activities on an unstable surface or using a narrow BOS (Westcott et al. 1998b). Although balance training has been shown to be effective clinically, only limited studies have been conducted to investigate balance training only for children with CP (Hartveld & Hegarty 1996; Shumway-Cook et al. 2003; Ledebt et al. 2005; Woollacott et al. 2005). These studies have utilized computerised balance training , which is different from the traditional clinical balance training. Two studies have used weight shifting protocols with visual feedback, which is primarily APA training (Hartveld & Hegarty 1996; Ledebt et al. 2005).

Hartveld and Hegarty (1996) hypothesised that standing balance and weight shifting training on the moveable Compex board, using home computer systems and games, improves the standing balance of children with diplegic CP. The study was an AB single-case experimental design. Four ambulant children, aged 5 to 16 years, were advised to practice multi-directional weight shifting for 30 minutes per day. Balance was measured by timing bilateral standing without support for two children and by timing unilateral standing for the other two children. These timing measurements only reflected the ability to stand longer, which is mainly an endurance measure, rather than reflecting the children's functional ability to balance and weight shift. Furthermore, data was visually analysed through trends of increased and decreased time. Because all four children demonstrated an increased trend during the treatment period, the improvement in standing balance was ascribed to the training intervention. Since the study design included only a single case, the generalizability of the results of this study is limited. However, the study was conducted in a natural setting and provided a realistic picture of the application of such a treatment in the daily life of a child with CP.

Ledebt et al. (2005) examined the effects of balance training with visual feedback on stance postural sway, weight shifting and walking in CP children. Ten hemiplegic CP children, who were classified as level I on the GMFCS, aged between 5 and 11 years, were randomised into two groups. Children in the intervention group undertook three 30-minute balance training sessions per week for a period of six weeks in a laboratory setting. The balance training comprised the performance of static and dynamic tasks on a stable force plate. The static task involved keeping the COP, represented by a red dot, in front of the children at eye level within a target area. The three dynamic tasks were performed by moving the dot [the COP] towards the target areas in each task. Children were assessed pre-training, post-training and after four weeks. Standing balance was assessed by measuring the performance in tasks, whereas walking was assessed by a four-meter walkway with two force plates.

During static standing, the amplitudes of the COP sway in the intervention group significantly decreased with time for the forward and backward [$p = 0.039$ and $p = 0.026$, respectively] directions. Moreover, during dynamic standing, the amplitude of the COP sway increased in the forward and backward [$p = 0.002$ and $p = 0.027$, respectively] directions and towards the non-paretic side [$p = 0.021$]. The step length asymmetry significantly decreased with time during walking [$p = .021$]. The study concluded that balance training for children with CP and visual feedback increases voluntary weight shifting, decreases postural sway during standing and decreases the asymmetry in step length while walking (Ledebt et al. 2005). Although the results provided valuable information regarding the effect of weight shifting on walking, a sample size of 10 is considered small and this has limited the generalizability of the study.

Two other studies have employed perturbation training with a mobile force plate to train RPA in children with CP (Shumway-Cook et al. 2003; Woollacott et al. 2005). Both studies used the same training protocol of a moveable force plate {NeuroCom International} with a total of 100 perturbations per day for 4–6 min at a rate of 12–24 cm/s for 5 days. Both studies examined six children with spastic CP aged between 7 to 12 years with GMFCS level II–I. COP sway area and time to stabilization were measured following a perturbation on the force plate (Shumway-Cook et al. 2003; Woollacott et al. 2005) and the EMG recordings of muscle activity were used to recover stability after perturbations (Woollacott et al. 2005). Shumway-Cook et al. (2003) reported a significant decrease in the COP sway area and time to stabilization following intervention [$p < 0.01$] and after a period of one month [$p < 0.01$] compared to pre-training. Moreover, improvements ranging from 2.94% to 11.76% were reported after training in dimension D [standing] of the gross motor functional measure [GMFM] (Shumway-Cook et al. 2003). According to Woollacott et al. (2005), no change or decreased onset latency for gastrocnemius and tibialis anterior were observed following perturbation training. Moreover, the results showed decreased contraction amplitude of the gastrocnemius for hemiplegic and diplegic children and decreased contraction amplitude of the tibialis anterior for diplegic children following perturbation training (Woollacott et al. 2005).

Improvements were reported in balance and postural control following computerised balance training for children with hemiplegic and diplegic CP with GMFCS level I–II. Specific improvements in weight shifting and gait (Ledebt et al. 2005), balance recovery of stability and muscle activation patterns (Shumway-Cook et al. 2003; Woollacott et al. 2005) and improvements in GMFM were reported for children with CP (Shumway-Cook et al. 2003). These improvements were seen immediately after training (Shumway-Cook et al. 2003; Ledebt et al. 2005; Woollacott et al. 2005), and after one month for children with CP (Shumway-Cook et al. 2003; Woollacott et al. 2005). The computerised balance training appears to be an effective method for improving balance in children with CP; however, none of these studies compared computerised balance training to traditional balance training.

Recently, it has been suggested that postural control training should involve activities to enable children with CP to explore new movements without an external stimulus through perturbation challenges (Dusing & Harbourne 2010). Therefore, weight shifting training with visual feedback while being involved in a fun game without the fear of external perturbations is more favourable for children with CP. Thus, further research needs to be conducted to investigate how weight-shifting training for children with CP can incorporate fun activities and video games.

2.3.2 Virtual reality balance training

Virtual reality is a computer-generated environment that utilizes visual and haptic feedback through the use of displays, headgear, body suits and other peripherals, where a person can interact and be transported virtually into that environment. The use of virtual reality in rehabilitation for CP children has been studied in the literature (Reid 2002; Reid 2004; Bryanton et al. 2006; Brien & Sveistrup 2011).

Reid (2002) proposed a theory of the effect of virtual reality immersion on the self-efficacy of children with CP. When a child interacts with a virtual environment that is enjoyable, he/she becomes engaged in that environment. Thus, the child will practice a new movement, creating a sense of mastery in the activity, leading to an increased feeling of self-efficacy (Reid 2002). In addition, virtual reality influences the playfulness of children with CP, enabling them to become creative and challenge themselves, thereby automatically increasing their motivation (Reid 2004).

Bryanton et al. (2006) tested the effect of virtual reality environment on children with CP while performing strengthening exercises. Ten children with CP {GMFCS level I, II} between the ages of 7 and 17 years old were asked to perform ankle dorsiflexion exercise in both the conventional and virtual reality settings. The ankle dorsiflexion ROM was calculated with the electro-goniometer. Children with CP when trained with virtual reality strengthening exercises exhibited an increase in ankle ROM and control of ankle dorsiflexion compared to when trained with conventional strengthening exercises (Bryanton et al. 2006). This is due to the feedback from the virtual reality where children expressed high attention to the exercise to achieve a score in the virtual game. Unlike the conventional settings where no feedback is given apart from the therapist's verbal instructions. Therefore, children reported a higher level of enjoyment with the virtual reality exercise programme and parents observed their children's increased motivation to complete this exercise programme (Bryanton et al. 2006).

Brien and Sveistrup (2011) studied the use of virtual reality in balance training for children with CP. Four adolescents with CP and GMFCS level I undertook an intensive daily session of virtual reality intervention for 90 minutes, 5 days a week. The virtual reality training included dynamic standing balance, weight shifting in standing, unilateral standing, reaching away from the centre of gravity, squatting and jumping, and side stepping. Assessments were conducted using the Community Balance and Mobility Scale [CB&M], six-minutes-walk test [6MWT], Timed Up and Down Stairs [TUDS] and Dimension E of the GMFM. Visual analysis showed an increase in trends in response to the intervention in the CB&M scores and 6MWT, which were maintained in the follow-up phase. All participants showed statistically and clinically significant changes on the 6MWT and CB&M from the baseline to the follow up. It was concluded that short, intense virtual reality intervention improves functional balance and mobility in adolescents with CP and these improvements were maintained one month later (Brien & Sveistrup 2011). An intensive virtual reality programme may be beneficial with increased frequency and magnitude. However, it may not be practical to train for 90 minutes daily, at home or at a clinic.

Active gaming systems, which are considered a form of virtual reality because they provide visual feedback, are less costly than true custom-designed virtual reality systems. This has evoked researchers' interest in gaming's clinical effects, which resemble the effects of virtual reality . The advantages of active gaming systems are as follows: 1) they are commercially available systems, 2) they can be used for home exercise programmes and 3) they provide opportunities for children with disabilities to participate with their TD peers. The Nintendo Wii is an example of an active gaming system that can be used for children with CP.

The nature of Wii games offers some sensory information that the child learns to react with a motor task. For example, the display of a game character and game instructions provides the visual sensation, the sounds and music provide the auditory sensation, the movement of limbs during the game provides proprioception sensation and the sense of legs on the WBB provides tactile sensation. All this sensory information which the child gets from playing the Wii games is used to achieve a motor voluntary movement to play, and the sensation feedback the child receives from the game directs his/her movement by showing how the players score points. The cycle of sensory information that the children get from the virtual reality world allows them to interact and learn.

In summary, postural control training should incorporate activities that enable children with CP to explore new movements without an external stimulus. There is an evidence to show that computerized balance training with virtual reality is effective for children with CP. Active gaming, such as the Wii game, is a form of virtual reality that can be used for balance training for children with CP. These possible rehabilitation interventions needs to be assessed for effectiveness. Therefore, considering how postural control can be assessed and what outcomes can be used to indicate postural control needs to be discussed.

2.4 Postural control assessment

2.4.1 Postural sway

The oscillation of the COM or COG over the BOS is called postural sway (Alexander & Pier 1998). This oscillation is controlled by the postural control system, presented in the position of COP. Therefore, changing the position of COP over time is a commonly used measure of postural sway, which has implications regarding the nature of the neurological and biomechanical mechanisms of postural control (Winter 1995; Lafond et al. 2004). Postural sway is affected by numerous factors and disorders, such as injury, aging and pathology, which alter the body's ability to adapt to changing stimuli. These interruptions to the postural control system lead to abnormal postural responses, instability or unsteadiness and impaired reaction times (Alexander & Pier 1998). Accordingly, they increase postural sway when an individual is standing upright.

The COP movement during standing, which represents postural stability, is mainly assessed using a force plate (Samson & Crowe 1996). Several force plates have been developed to quantify postural stability (Lafond et al. 2004). During bilateral standing, the COP falls between the feet; however, it varies depending on the weight distribution of each foot (Winter 1995). When one force plate is used, the net COP is the available output. However, when two force plates are used, two separate COPs under each foot will quantify the changes of the COP within each foot (Winter 1995). In this case, the location of the COP under each foot represents the neural control of the ankle joint muscles. For example, the COP will move anteriorly during ankle plantar flexion and posteriorly during dorsiflexion. Moreover, the COP will move laterally depending on inversion and eversion of the ankle joint (Winter 1995).

COP measurements include the speed of COP movement over time ‘COP velocity’, length of COP points travelled over time ‘COP path length’ and area that COP moves within ‘COP sway area’ (Kuukkanen & Mälkiä 2000). These measurements or parameters of COP have been used in the literature to identify the differences in sway with regard to age groups, sensory conditions, pathology and its association with the risk of falls (Overstall et al. 1977; Mizrahi et al. 1989; Nies & Sinnott 1991; Lafond et al. 2004; Demura et al. 2005; Lin et al. 2008).

2.4.2 Postural sway in children

When comparing children and adults, children were found to have an increased and more variable postural sway at a higher velocity than adults (Forssberg & Nashner 1982). This may be due to incomplete maturation of the sensory systems. Therefore, postural stability increases with age in the form of decreased variance, velocity and frequency of COP sway during standing (Odenrick & Sandstedt 1984; Riach & Hayes 1987; Taguchi & Tada 1988; Riach & Starkes 1994; Wolff et al. 1998).

The age of when children start to show a decrease in postural sway was debatable between researchers. Riach & Hayes (1987) found that postural sway amplitude of the root mean square [RMS] decreases between the ages of 2 to 14 years (Riach & Hayes 1987), while Odenrick & Sandstedt (1984) found that this decrease occurs between the ages of 3 to 17 years of age. Similarly, a few studies found that postural sway velocity decreases between the ages of 4 to 15 years (Taguchi & Tada 1988; Riach & Starkes 1994), while another study found that this decrease occurs between the ages of 5 to 18 years (Wolff et al. 1998). AP postural sway decreases by 5% and ML postural sway decreases by 25% in children between the ages of 5 to 18 years (Wolff et al. 1998). In addition, postural control develops faster over the AP axis than the ML axis (Hong et al. 2008).

Gender-related differences in the development of postural sway have been studied in literature. Females between the ages of 9 to 10 years have more ML instability than males (Nolan et al. 2005). However, females develop adult-like AP control with vision between the ages of 12 to 13 years, whereas, males of the same age fail to demonstrate this development. On the other hand, males develop AP control over two different time periods, that is, at the ages of 9 to 10 years and 15 to 16 years (Nolan et al. 2005).

As discussed earlier (section 2.2.2), due to the development of different sensory systems at different rates, children undergo transitional periods of postural control at 4 to 5 years (Foudriat et al. 1993), 6 to 7 years (Baumberger et al. 2004) and 8 to 10 years (Figura et al. 1991). However, the theoretical critical age for postural control development in children is between the ages of 3 to 8 years (Forssberg & Nashner 1982; Woollacott et al. 1987; Rine et al. 1998).

2.4.3 The reliability of COP parameters

Although they are commonly used, force plates, may be subject to measurement errors. These errors could be avoided when the equipment is tested for reliability. There are several types of reliability studies: intra-session, inter-session and inter-ratter (Bauer et al. 2008). The type of reliability is important when determining the effectiveness of an intervention (Nies & Sinnott 1991; Corriveau et al. 2000; Lafond et al. 2004; Bauer et al. 2008; Hadian et al. 2008; Lin et al. 2008; Santos et al. 2008).

Intra-session reliability refers to immediate test-retest reliability, related to the random variability of the measurement, and is an indication of the reproducibility of a measure within one session. This type of reliability is important to determine the effectiveness of the intervention (Corriveau et al. 2000). Inter-session reliability is the consistency among measures over a set timeframe and indicates the reproducibility of measurements among multiple sessions, usually on different days (Corriveau et al. 2000). Inter-ratter or inter-examiner reliability is the ability of different examiners to conduct a measurement consistently throughout a study. It is primarily related to the ratter and their data collection protocol. However, owing to the simplicity of the equipment, task and instructions, this type of reliability is unlikely to be problematic (Corriveau et al. 2000; Santos et al. 2008).

The majority of reliability studies of postural stability have used intra-session reliability (Corriveau et al. 2000; Lafond et al. 2004; Bauer et al. 2008; Pinsault & Vuillerme 2009). Only a few studies have conducted both intra- and inter-session reliability (Lin et al. 2008). Intra-session reliability has been shown to have higher reliability values than inter-session reliability (Lin et al. 2008).

Although inter-ratter reliability may not be used in COP-based postural control studies, the protocol and procedure of data collection may be varied. Thus far, no standardised measurement protocol has been established. Therefore, COP parameters' reliability has been tested widely in the literature with different force plates, different feet positions, different number of trials with different test durations and different COP parameters for each study (Ruhe et al. 2010). The factors that can possibly affect the reliability of COP parameters' reliability are discussed below.

2.4.4 Factors affecting the reliability of COP parameters

2.4.4.1 Subject demographics

Most COP reliability studies show the basic physical differences, such as height and weight and body mass index [BMI], among the participants tested. The COP parameters, such as mean velocity or range, are affected by the subject's height (Chiari et al. 2002) and weight (Hue et al. 2007). Therefore, addressing the link among subjects' physical demographics and COP parameters tested is suggested when performing a reliability study (Ruhe et al. 2010).

The reliability of COP parameters was not influenced by gender because most research was conducted on mixed-gender populations. The COP measures' reliability was different among different age groups (Hageman et al. 1995; Doyle et al. 2004; Demura et al. 2008). This is owing to the variability in the balance ability of participants of different ages, especially among children, young adults and older adults, where each age group has different mechanisms of postural control. Therefore, reliability studies performed on an adult population may not necessarily apply to other age groups.

2.4.4.2 Experimental setup

The instructions given to participants during testing may influence the results of the COP parameters investigated (Zok et al. 2008). The most commonly used instructions were either 'stand quietly' or 'stand as still as possible'. Depending on the instruction used, the COP parameters showed 8–71% variation (Zok et al. 2008). Using the instruction 'stand as still as possible' is recommended because it showed narrower confidence intervals, which indicates a higher level of reliability (Ruhe et al. 2010).

Ensuring consistency of the standing posture while recording data, including the position of the feet and arms, is essential in reliability studies. It is suggested that the arm is positioned at the side of the body, thereby maintaining the natural COP position from a biomechanical perspective (Ruhe et al. 2010).

Most reliability studies use various foot positions during posturography testing. Some studies have investigated the effect of the foot position on COP parameter reliability (Hill et al. 1995; Chiari et al. 2000; Santos et al. 2008). A wide foot position increases the passive stability of the musculoskeletal system and decreases the active neural control, thereby increasing the reliability coefficients (Chiari et al. 2000). Based on 25-second recordings, Hill et al. (1995) showed that the measurements taken when participants are standing with their feet together are less reliable than those taken when they are standing with their feet apart with an interclass correlation coefficient

[ICC] ≤0.55 (Hill et al. 1995). Furthermore, Santos et al. (2008) showed significantly higher correlation coefficients for normal stance compared to narrow stance based on 7 repetitions of 60-second recordings (Santos et al. 2008). However, a higher reliability value was obtained for narrow stance than normal stance when data from a single 30-second trial was compared (Chiari et al. 2000). No standardised foot position should be followed; however, consistency while testing must be maintained, even though the position of the foot will be altered when stepping on and off the force plate during breaks (Ruhe et al. 2010).

2.4.4.3 Sampling frequency

Few studies show that the reliability of COP measures is influenced by the chosen acquisition frequency of the data set (Schmid et al. 2002; Raymakers et al. 2005). Fundamentally, sampling frequency is the amount of COP points detected while recording. It is expected that the more the number of COP points detected, the better the analysis of COP movements. In the literature, sampling frequencies vary from 10 to 200 Hz (Hill et al. 1995; Chiari et al. 2000; Lafond et al. 2004; Doyle et al. 2007; Bauer et al. 2008; Doyle et al. 2008; Hadian et al. 2008; Santos et al. 2008; Pinsault & Vuillerme 2009) and COP reliability was found to vary across similar experimental setups partially due to the differences in the chosen frequencies. Some COP parameters are sensitive to the selected sampling frequency. For example, mean COP displacement measures, such as mean velocity or mean amplitude, are less sensitive to different sampling frequencies (Schmid et al. 2002). When a sampling frequency of 50 Hz was used, the COP mean velocity and path length was 26.1% greater than when a frequency of 10 Hz was used (Raymakers et al. 2005). However, the reliability of COP mean velocity was not significantly affected by different frequencies ranging from 64 to 200 Hz (Doyle et al. 2007; Hadian et al. 2008; Pinsault & Vuillerme 2009). Although the chosen sampling frequency depends on the COP parameters chosen, a sampling frequency of 100 Hz is recommended (Ruhe et al. 2010).

2.4.4.4 Sampling duration

The number of trial recordings and their duration appear to be important factors in the reliability of COP measures. The ideal trial duration time has been a subject of debate in the literature. Earlier studies suggest that sample durations of 10–60 seconds may provide reliable data depending on the observed COP measures (Goldie et al. 1989; Letz & Gerr 1995; Le Clair & Riach 1996; Schmid et al. 2002). Le Clair and Riach (1996) suggest that a trial duration of 20–30 seconds will provide reliable data based on the assumptions that standing strategy alternations are adapted with time and an increased trial duration of more than 30 seconds will increase variability. Lafond et al. (2004) found that a duration of 60 seconds is sufficient for a reasonable COP parameter reliability, because there is little difference in the ICC values between trials lasting

60 and 120 seconds, which means that an extra 60 seconds is unnecessary. In contrast, other studies have concluded that a duration of 90 to 120 seconds is optimal to reach correlation coefficients of ≥0.75 for COP parameters and that 10–30 seconds is not sufficient to obtain reliable COP parameters (Carpenter et al. 2001; Doyle et al. 2005; Weir 2005; Santos et al. 2008).

Therefore, in summary, to obtain good reliability for most COP parameters, a sampling duration of 90 seconds is suggested (Ruhe et al. 2010). However, owing to the diversity of COP parameters measured and the methods used to obtain data, the trials of only the same duration and COP measures can be compared (Le Clair & Riach 1996). Owing to the possible effects of fatigue or boredom, especially in a population with balance impairments, increasing the number or duration of trials in a single day needs to be considered carefully. Moreover, it must be kept in mind that most of the extant studies involved adult participants, and it may not be possible for participants belonging to other age groups, such as children or elderly, to stand for more than 60 seconds.

2.4.4.5 Number of repetitions

Besides trial duration, the number of repetitions is an important factor for gaining acceptable reliability among COP parameters. These two factors are subjective to the research based on the population tested. Therefore, the number of repetitions used in reliability studies varied between two (Kitabayashi et al. 2003), three (Salavati et al. 2009), four (Doyle et al. 2007) and seven (Santos et al. 2008) repetitions, which yields acceptable reliability for the majority of COP parameters.

Increasing the number of trials may provide more reliable data; however, in a clinical setting, it is impractical to ask elderly people or individuals with limited balance ability to perform 7 to 10 trials. Therefore, an average of 3 to 5 trials is acceptable and practical to obtain reliable COP parameters (Ruhe et al. 2010).

2.4.4.6 COP Parameters

Most COP parameters tested in reliability studies show an acceptable level of reliability with a variety of degrees between parameters. Studies have shown intra-session reliability results of different COP parameters.

Extant studies have shown that COP velocity may be the most reliable parameter, whereas COP sway area may be the least reliable (Lafond et al. 2004). Lin et al. (2008) found greater reliability values in COP mean velocity, COP sway area and RMS distance. Although both Lafond et al. (2004) and Lin et al. (2008) used a similar participant group and testing conditions, they used different statistical analysis methods, which may be the reason for the different reliability values.

Moreover, Bauer et al. (2008) obtained good to excellent reliability of COP parameters, including mean sway area, COP length, ML and AP sway.

It is suggested that the fractal dimension be used as a COP parameter because it is different from traditional COP measures (Doyle et al. 2005). Fractal dimension is a technique used in dynamical systems, which provides an indication of the complexity of a signal while describing its shape. For example, a signal with a fractal dimension equal to one means that it is a stationary signal over time, whereas a signal with a fractal dimension equal to two means that this is a signal that oscillates equally over time (Doyle et al. 2005). Therefore, the number of fractal dimension changes describes the changes in signals. This may indicate control strategy changes when participants are standing by analysing the COP patterns. The reliability of fractal dimension as a measure for the COP was tested and compared to the traditional COP parameters (Doyle et al. 2005). Doyle et al. (2005) noted that the reliability of fractal dimension as a traditional COP measure was higher [ICC2,1 = 0.62–0.90] than the reliability of mean velocity, [ICC2,1 = 0.05–0.71]. However, the sampling duration for recording data was 10 seconds, which is an insufficient timeframe to gain reliable data (Lafond et al. 2004). In contrast, Santos et al. (2008) showed that fractal dimension reliability values were comparable to traditional COP measures, with an acceptable sampling duration of 60 seconds (Santos et al. 2008).

Parameters of minimal, maximal or peak-to-peak readings, which use only one or two data points of the entire recorded data, should be avoided because they are subject to great variances with lower reliability values (Ruhe et al. 2010). It can be concluded a sufficient number of repetitions and adequate sampling duration will ensure acceptable reliability for all COP parameters. Furthermore, the selection of COP parameters depends upon the specific research purpose. This should include both distance and time, such as mean velocity or COP length, to gain a reliable description of the COP excursion(Ruhe et al. 2010).

2.4.4.7 Visual conditions

To maintain balance while standing upright, individuals mainly use the visual system. Therefore, the absence or presence of visual information has an impact on steadiness. Simoneau et al. (1995) showed the effect of the visual system on postural control, as measured by the percentage displacement of the COP, with a 41% increase in COP movement during the absence of vision. This finding led researchers to investigate the effect of visual information on the reliability of COP parameters. The results of these studies have shown that the COP parameters measured when participants' eyes were closed were more reliable than when their eyes were open (Geurts et al. 1993; Hageman et al. 1995; Chiari et al. 2000; Lafond et al. 2004; Doyle et al. 2005; Doyle et al. 2007; Bauer et al. 2008; Santos et al. 2008). This was surprising because it was expected that participants would find it harder to maintain postural stability when their eyes are closed. However, loss of vision may increase muscle stiffness, which may be the reason behind the high reliability of measures in the eyes closed condition (Redfern et al. 2001). In addition, this result may also be owing to the use of improved technical equipment or rigorous scientific procedures in conducting the studies (Ruhe et al. 2010). The removal of visual input is necessary when evaluating postural control to detect differences between healthy subjects and those with sensory impairments, such as vestibular, proprioception or sensory-motor impairments. In addition, it is recommended that data be collected under both conditions eyes open and eyes closed for permitting a reliability study or for outcome measurements (Ruhe et al. 2010).

In summary, postural control is mainly assessed with laboratory force plates. Other platforms can be used as well, however they need to be tested for reliability before they are used for measuring the effectiveness of a balance intervention. In addition, the factors that can possibly influence the reliability results should also be considered.

2.5 Summary

Children with CP have presented with postural control deficit owing to a wide range of impairments of the body structure and function including; muscle tone impairments, musculoskeletal imbalances and conflicting sensations. In comparison between TD children and children with CP regarding the reaction to conflicting sensory information while performing balance activities, children with CP react in the same manner as TD children under the age of 7 years (Nashner et al. 1983). In relation to postural control adjustments, children with CP between the ages of 8 to 13 years respond to perturbation similarly to TD children between the ages of 4 to 8 years (Chen & Woollacott 2007). While reaching forward, children with CP appear to show increased COP path length, in ML direction rather than in AP direction (Zaino 1999; Liu et al. 2000). Furthermore, the motor coordination pattern of TD children during standing in a crouched position and reaching forward was similar to that of children with CP, who usually adapt their posture (Thorpe et al. 1998). Therefore, children with CP experience daily challenges in maintaining their balance. This feeling of instability restrict their participation in social activites with TD peers and make them prefer more sedentary activities (Imms 2008). Consequently, children with CP would probably benefit from balance training as a part of their rehabilitation, especially if it covers the three domains of ICF model of impairments, activity limitations and participation restrictions.

Weight shifting practice through computerised balance training has been shown to be effective in improving weight shifting during gait (Ledebt et al. 2005), balance recovery of stability and muscle activation patterns (Shumway-Cook et al. 2003; Woollacott et al. 2005), and improvements in GMFM for children with CP (Shumway-Cook et al. 2003) for children with CP. In addition virtual reality environment increases the feeling of self-efficacy (Reid 2002) and positively influences the playfulness of children with CP (Reid 2004), thereby enabling them to become more creative. Therefore, computerized balance training with virtual reality have been shown to be effective in improving the functional balance mobility and walking ability of children with CP (Brien & Sveistrup 2011).

Active gaming, such as the Nintendo Wii, is a virtual reality tool that can be used for rehabilitating different neurological population, including children with CP. Wii Fit games, in specific, includes balance exercise that train weight shifting with visual feedback. Such games can provide similar benefits of the computerised balance training with virtual environment for children with CP. In addition, these games are commercially available where children with CP can share the game with TD peers, which can possibly increase social participation. However, this possible rehabilitation intervention needs to be assessed for effectiveness.

Postural control is presented by the movement of COP over time which is called postural sway. Postural sway has implications regarding the nature of the neurological and biomechanical mechanisms of postural control (Winter 1995; Lafond et al. 2004). The gold standard laboratory force plate provides COP parameters to quantify postural control (Lafond et al. 2004). However, force plates are subject to measurement errors which needs to be tested for reliability before they are used for postural control assessment. Therefore, when using the WBB as a postural control assessment tool, it should be tested for reliability as well. In addition, the factors that can possibly influence the reliability of COP parameters' results should also be considered.

This chapter has demonstrated a background of the main elements of this research including children with CP postural control characteristics, what is the possible postural control interventions and how it will be assessed. This has provided a base of knowledge to direct the literature behind how to use Wii games as a postural control intervention and WBB as a postural control assessment for children with CP.

Chapter 3: Literature review

This chapter includes the literature relating to the research questions and the literature search strategies. It has two parts, one about the Nintendo Wii games, specifically Wii Fit games, and the literature relating to using them in rehabilitation of different populations, including children with CP. The other part is about the literature relating to using the WBB for balance assessment in rehabilitation, including the reliability and validity of its measurements. In addition to how the WBB has been used by different researchers as an assessment tool.

3.1 Nintendo Wii

The Nintendo Wii is an interactive virtual reality video game system, which was introduced in the US and the UK at the end of 2006 (Blakely & Sabbagh 2006). The Wii comprises a console, Wiimote and sensor bar (Figure 3.1). The console has a DVD drive for games discs. The Wiimote is a wireless motion-sensitive controller shaped like a television remote, which communicates with the sensor bar through an infrared camera within the forward tip. The sensor bar, which should be placed on top of the television set and plugged into the Wii, contains very small infrared light-emitting diodes [LEDs]. The Wiimote has an accelerometer that senses motion and positioning and sends this information to the Wii console via Bluetooth technology during gameplay.

Figure 3.1: The Nintendo Wii set up

While playing the games, an avatar characterises the player and mirrors the player's movements within the virtual environment (Deutsch et al. 2008). Therefore, the player needs to physically perform the action to control and play the game. This virtual reality environment provides both entertainment and indoor physical activity. There are various Wii games that can be played individually or with other players and are suitable for different age groups. The scores for each player on each game are saved on an secure digital card in the console.

The most popular Wii games are Wii Fit and Wii Sports (Nintendo 2015). Wii Sports includes sports games, such as tennis, golf, baseball, boxing and bowling. These games are usually played using the Wiimote because most of them focus on the movement of the upper limbs (Figure 3.2). Wii Fit is a fitness game with many different aerobic, strengthening, yoga and balance exercises, which is usually played using the WBB because it requires shifting weight in different directions. Both the Wiimote and WBB are tools of communication, which transfer the data of the player's movement to the Wii console.

Figure 3.2: Wii Sport and Wii Fit games

The Wii Fit games were mainly designed for fitness exercises ranging from slow cool down yoga games to fast worm up aerobic games, in addition to strengthening games for each muscle group. Yoga and strengthening games are played with an instructions of the avatar personal trainer, who also demonstrate the exercise. These games mimic the fitness gym exercises. However, balance and aerobic exercises are played with the Mii character, which can be customised to the player preference, and each game has different visual graphics depending on the purpose of the game. For example, the Mii character in the balance game ‘Penguin Slide’ presented like a penguin which slides over an iceberg to catch flying fishes. In this game the player stands on the WBB and shifts weight to right and left, representing the movement of the iceberg that the penguin slides across. Whereas, in the ‘Soccer Heading’ game the Mii character is a football player resembling the player standing, while heading the balls thrown at him by other characters. The player shifts their weight according to whether the balls come from the right or the left. Therefore, the player’s movement can be different in each game to encourage weight shifting and to focus on standing balance while the player concentrates on the game.

The WBB is an accessory of the Wii; in particular, it is required to play all the Wii Fit games. The WBB connects to the Wii console via Bluetooth. The WBB is a pressure-sensitive board that the player stands on and leans in different directions to control the movement of their character in the game (Deutsch et al. 2008). The WBB contains four sensors, located on each corner of the WBB (**Figure 3.3**), which detect changes in weight distribution in four directions. The WBB can detect small changes in weight distribution and communicates with the Wii console to represent these changes to give visual feedback of the player’s movement. This piece of technology has raised the interest of many therapists because patients can perform beneficial movements with good visual feedback, all while enjoying playing a game. Thus, there have been some studies to test the effect of using Wii Fit games with WBB as a balance training tool for rehabilitation.

Figure 3.3: Wii Balance Board and the location of sensors

The WBB sensors are used to assess the force distribution and thus COP movements, similar to a laboratory force plate (Clark et al. 2010). This characteristic of the WBB was of interest to another group of researchers, who investigated the ability of the WBB to measure balance and produce valid and reliable data. The WBB possesses technologically advanced features, and its applicability, portability and low cost have attracted the interest of researchers. It has been tested as a balance measurement tool both with and without the Wii Fit game. Therefore, the studies found in the literature are discussed under two main categories: 1) using the WBB as a balance assessment tool to measure COP parameters and 2) using the Wii Fit games as balance rehabilitation tools to improve balance.

3.2 Literature search

The literature search consisted of searching seven main databases which were; AMED, CINAHL, EMBASE, MEDLINE, Web of Science, PubMed, and Science Direct. In addition to the University of Southampton database of electronic and print items from subscribed academic resources, known as 'DelphiS'. The search terms were divided to four main searching groups, in each group a list of alternative searching terms. The main four searching terms were selected from the research title, which were; Wii Fit balance games, standing postural control, children with CP, and Wii balance board. Each searching term from each group was used in database search with Boolean operators of 'or' or 'and' or both (**Figure 3.4**). The number of studies found in each database with each search term is presented in **Table 3.1**

Studies were selected to be discussed in the literature review, based on the following inclusion criteria; 1) English language peer review publication between the years 2008 and 2015, 2) studies investigating the use of Wii Fit games as balance training intervention to improve balance for rehabilitation proposes with populations identified with poor balance control, 3) studies tested the capability of using the WBB as a balance assessment tool {including testing the validity and reliability of WBB' data}, or have used it as an outcome measure of balance.

However, studies were excluded if they were; 1) poster abstracts, 2) If the study does not use the Wii Fit games for balance training, but for other purposes, such as fitness, energy expenditure, or education, or 3) If the study Includes using Wii games other than Wii Fit {e.g. Wii Sports or Wii U}, other forms of videogames like Sony PlayStation, or designed games which are not commercially available. Figure 3.5 presents a flow chart of this process, highlighting the number of studies selected for the literature review.

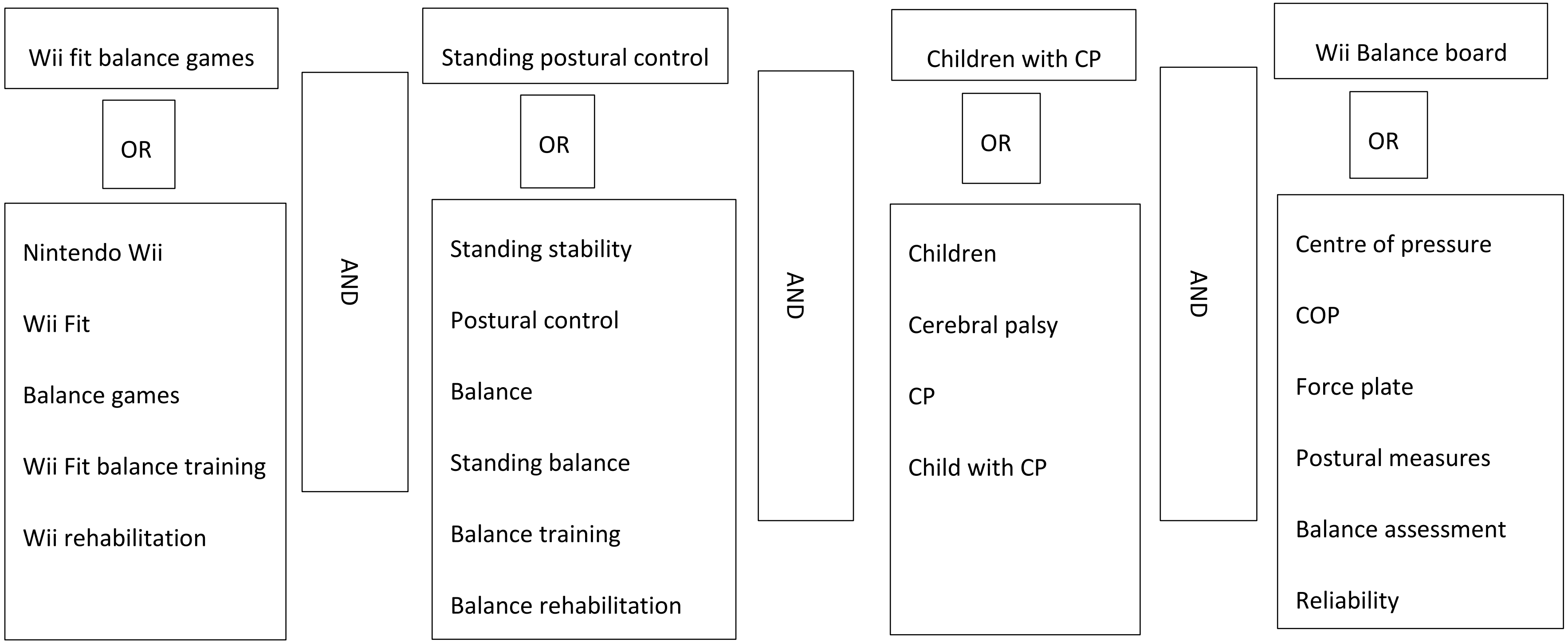


Figure 3.4: Literature search terms using Boolean logic 'OR' 'AND'

Table 3.1: The number of studies found in each database with each searching term

	Search term	Articles found in each database							
		DelphiS	AMED	CINAHL	EMBASE	MEDLINE	Web of Science	PubMed	Science Direct
1	Nintendo Wii or Wii Fit	515	62	209	1157	291	840	307	128
2	Wii Fit or balance games	2921	60	107	487	139	296	402	604
3	Wii Fit games	196	7	13	42	20	201	82	38
4	1 and 2	185	31	93	478	115	582	164	23
5	3 and 4	135	7	13	42	20	392	82	38
6	Wii rehabilitation or Wii fit balance training	283	19	43	30	51	372	206	393
7	Postural control or standing stability	58847	825	1622	12221	319	80115	13756	5233
8	7 and 2	186	5	8	54	1	133	100	2
9	7 and 3	42	1	2	7	0	107	26	7
10	7 and 6	99	2	2	5	0	171	51	2
11	Standing balance or balance	20031	3727	588	3711	1352	41087	4320	2699
12	11 and 4	138	23	3	25	6	78	27	7
13	11 and 5	79	6	3	2	4	63	12	6
14	11 and 6	296	8	3	5	4	100	26	3
15	Balance training or balance rehabilitation	69643	374	1456	4043	2053	57599	17633	3526
16	15 and 1	285	9	45	154	58	401	112	15
17	15 and 3	100	2	5	13	7	201	45	11
18	15 and 6	354	5	19	14	22	442	118	7

19	Children with CP or cerebral palsy	110700	2443	8958	71590	21395	81747	25677	5636
20	19 and 1	12	3	9	66	8	56	9	2
21	19 and 2	32	3	5	34	4	36	16	2
22	19 and 3	5	1	0	8	1	25	3	2
23	19 and 6	9	2	3	4	1	67	12	0
24	19 and 10	3	1	0	1	0	11	4	0
25	19 and 13	3	1	0	1	0	7	1	1
26	19 and 18	8	0	0	1	0	37	5	0
27	Wii balance board	591	14	49	235	81	145	103	48
28	Centre of pressure or Center of pressure or COP	695842	743	1505	19193	8915	42964	148684	13082
29	27 and 28	180	3	9	96	32	104	36	17
30	Force plate or Postural measures	76711	666	809	7226	2608	224910	9109	1953
31	29 and 30	86	0	3	29	7	74	19	4
32	Balance assessment	78158	238	535	1410	1215	88794	11641	5904
33	32 and 30	4522	15	25	123	59	3423	1128	52
34	33 and 29	716	0	1	4	1	22	8	3
35	Reliability and 29	16	0	3	38	9	30	9	4
Articles selected from each database		2179	42	71	304	112	1889	473	107

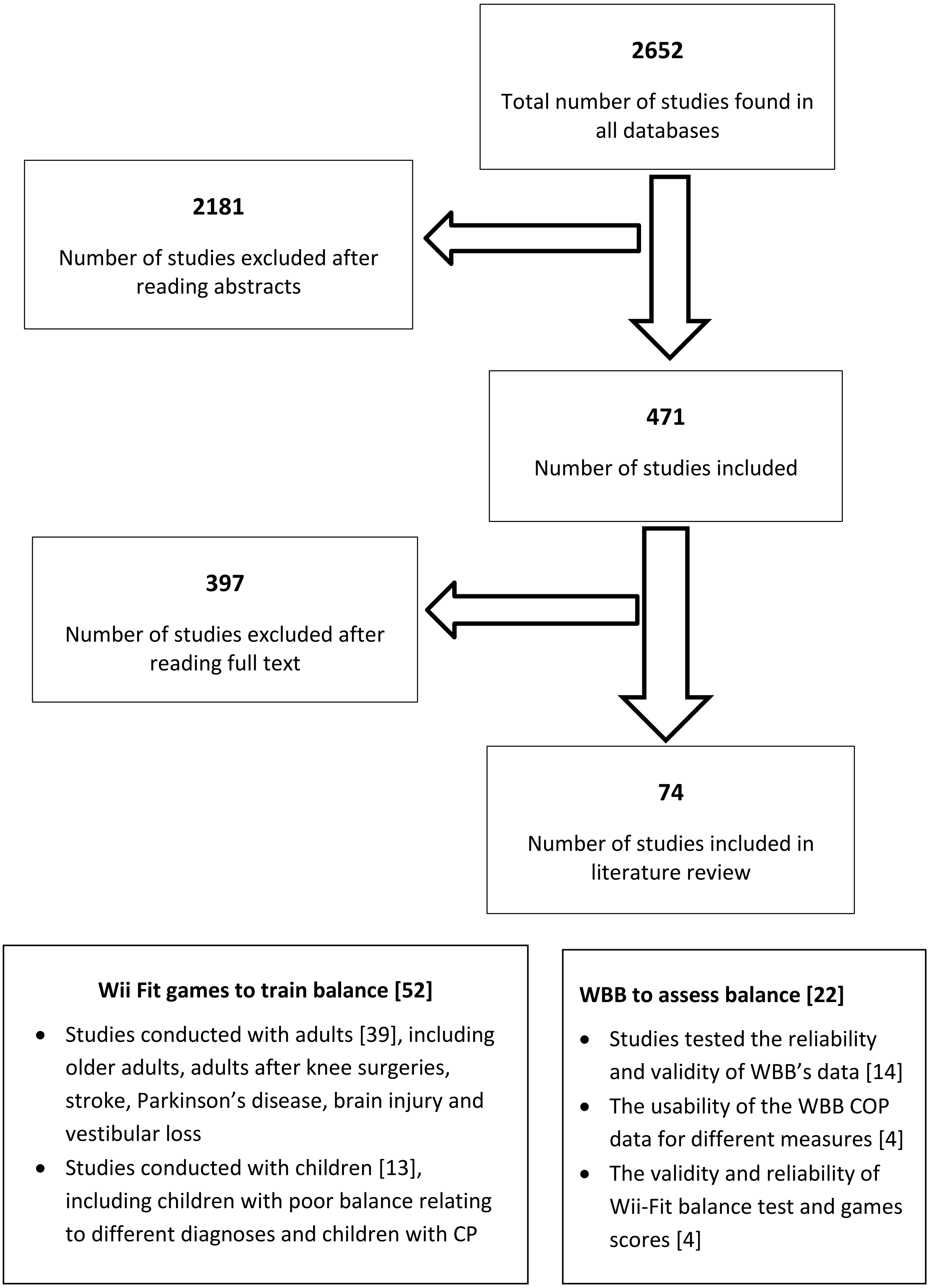


Figure 3.5: Flow chart of the process and the final number of studies in the literature review

3.3 WBB as a balance assessment tool

Since 2010, when the first study about the ability of WBB to provide valid and reliable outcomes of postural control was published, increased interest was observed in the literature. To date, there are 14 studies in the literature that have investigated the validity and reliability of WBB in providing comparable results to other laboratory measures using different populations. Four studies presented other benefits of WBB's COP data in informing clinical rehabilitation over and above postural control. The use of WBB alone to measure balance was mistaken with the use of WBB with Wii Fit game scores to assess balance be some researchers. Therefore, four studies that investigated the reliability and validity of the Wii Fit game scores and tests as a form of balance assessment are discussed.

3.3.1 The WBB data validity and reliability

Because the WBB communicates with the Wii console through wireless Bluetooth communication, the WBB can also communicate through Bluetooth with any computer. Thus, any computer with the appropriate software can be configured to use the data extracted from the four sensors of the WBB (Young et al. 2011). The chosen software should have the capability to extract data from the sensors to calculate the resultant COP coordinates and COP parameters can then be further calculated. In this manner, quantitative COP parameters can be used in research to measure balance.

Since 2010, the literature relating to the validity and reliability of WBB data for use in balance assessment has increased. Fourteen studies were identified, of which seven tested both reliability and validity (Table 3.2), five studies only tested validity (Table 3.3), and only two tested reliability (Table 3.4).

Twelve studies explored the validity of COP data obtained from WBB when compared to; laboratory force plate (Clark et al. 2010; Chang et al. 2013; Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Holmes et al. 2013b; Bower et al. 2014; Larsen et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Sgrò et al. 2014; Abujaber et al. 2015; Pavan et al. 2015), the Smart Balance Master [SBM] (Chang et al. 2013), the Baropodometer platform [BP] (Sgrò et al. 2014), and clinical functional balance tests (Bower et al. 2014). The validity results were based on the outcomes analysis of standing on each device {force plate or SBM or BP} and on the WBB separately (Clark et al. 2010; Chang et al. 2013;

Holmes et al. 2013b; Bower et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Sgrò et al. 2014; Abujaber et al. 2015), or standing on the WBB placed on top of force plate (Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Pavan et al. 2015). However, the study by Bower et al. (2014) was the only one that tested the correlation between the WBB's data of COP parameters and clinical functional balance tests, such as the Ten-meter Walk Test [10MWT], the Timed Up and Go [TUG], Step Test and the Functional Reach test [FRT]. Seven of these studies tested the reliability and the validity of COP data obtained from the WBB(Clark et al. 2010; Chang et al. 2013; Bower et al. 2014; Larsen et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Abujaber et al. 2015). Only two studies focused on the reliability of WBB's data relating to weight bearing asymmetry [WBA] while standing on two WBBs (Clark et al. 2011), and the capability of WBB to reliably assess balance in adults with impaired vision (Jeter et al. 2015).

The sample size in most studies ranged between 20 and 37 participants, where only three studies included fewer than 12 participants (Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Sgrò et al. 2014), and one study had 54 participants (Larsen et al. 2014). The participants recruited for these studies were young healthy adults (Clark et al. 2010; Clark et al. 2011; Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Park & Lee 2014; Sgrò et al. 2014; Pavan et al. 2015), older adults (Chang et al. 2013; Scaglioni-Solano & Aragon-Vargas 2014), older adults with total joint arthroplasty (Abujaber et al. 2015), adults with Parkinson's disease [PD] (Holmes et al. 2013b), adults post stroke (Bower et al. 2014), and children (Larsen et al. 2014). None of these studies compared the reliability and validity results between populations either based on age or pathology, except for that by Chang et al. (2013), which revealed that older adults showed higher reliability values than younger adults. They explained this difference as experience-related and not age-related, where younger adults have more experience with WBB than older adults. Even though, these studies presented evidence of the reliability and validity of data obtained from WBB when assessing balance across all these populations. However the research is still limited to healthy populations, only Holmes et al. (2013b) have considered adults with PD and Bower et al. (2014) tested adults post stroke. Therefore, more studies are required to test the validity and reliability of WBB with patient populations.

Various balance outcomes were calculated based on data obtained from WBB, such as; COP path length (Clark et al. 2010; Chang et al. 2013; Holmes et al. 2013b; Larsen et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Sgrò et al. 2014; Jeter et al. 2015;

Pavan et al. 2015), COP velocity (Clark et al. 2011; Huurnink et al. 2013; Bower et al. 2014; Park & Lee 2014; Jeter et al. 2015), maximum COP sway in AP and ML directions (Bower et al. 2014; Jeter et al. 2015; Pavan et al. 2015), mean WBA (Clark et al. 2011; Bower et al. 2014), and the vertical component of the ground reaction force [vGRF] (Yamamoto & Matsuzawa 2013; Abujaber et al. 2015). This shows the flexibility of WBB's data which can be used to calculate different outcomes of balance that can be used in assessment. However, all these laboratory outcomes were derived using different programmed software and algorithms designed by the researchers of each study. Most of the studies used custom written software, such as LabVEIW or MATLAB software, whereas only Park & Lee (2014) designed new user-friendly software called Balancia and showed the validity and reliability of COP length and velocity calculated using that software. Although the software and outcomes were different across the studies, the calibration protocol used by all of them was that suggested by Clark et al. (2010). This is because Clark et al. (2010) were the first to compare the validity and reliability of the COP path length obtained by the WBB with the COP path length obtained using a laboratory force plate. Details of the calibration of the WBB and calculation of the COP are presented in Appendix 1.

The validity and reliability of WBB's data was tested while participants were performing different static standing tasks, such as; double-leg stance with eyes open and eyes closed (Clark et al. 2010; Chang et al. 2013; Holmes et al. 2013b; Bower et al. 2014; Larsen et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Sgrò et al. 2014; Jeter et al. 2015; Pavan et al. 2015), feet together double-leg stance with eyes open and eyes closed (Holmes et al. 2013b), double-leg stance on foam surface with eyes open and eyes closed (Scaglioni-Solano & Aragon-Vargas 2014; Jeter et al. 2015), single-leg stance with eyes open (Clark et al. 2010; Chang et al. 2013; Huurnink et al. 2013; Larsen et al. 2014; Park & Lee 2014), single-leg stance with eyes closed (Clark et al. 2010; Huurnink et al. 2013; Park & Lee 2014). In addition, some dynamic standing tasks were also performed during testing, such as; sit-to-stand [STS] (Bower et al. 2014; Abujaber et al. 2015), mediolateral weight shifting (Bower et al. 2014), squatting (Clark et al. 2011), and jumping (Yamamoto & Matsuzawa 2013). Most studies were in agreement regarding the results of correlation values during single leg standing tasks which were lower than correlation values during double-leg standing tasks. However, Huurnink et al. (2013) showed high correlation between force plate and WBB with small differences in error when calculating COP length and velocity during single-leg standing. This shows that the WBB quantifies COP trajectory accurately during single-leg stance balance tasks. Therefore, the correlation variability seen in other studies during single-leg standing tasks is due to intra-subject variability and not the accuracy of the WBB or its measurements.

The variety of standing tasks presented in these studies, showed the practicality of the WBB in balance assessment. It also shows the validity and reliability of the WBB outcomes with different standing tasks. This gives clinicians and researchers more flexibility in assessing different aspects of stability with healthy and patient population. For example, the mean WBA calculated by two WBBs during squatting, in the study by Clark et al. (2011), is a good indicator for symmetrical weight bearing following weight shifting training especially for hemiplegic patients. However, the validity of the WBA data from two WBBs may need to be tested before considering it as a clinical measure. Furthermore, the vGRF calculated during jumping trials in the Yamamoto and Matsuzawa (2013) study, is another example of quantifying dynamic movement which can be used to evaluate sports performances.

The use of the WBB as a balance assessment tool has increased widely in literature. The validity and reliability testing of WBB data to be used in balance assessment has been a main focus of researchers. The studies discussed earlier have proven the accuracy of WBB measurements with different connecting software, different calculated outcomes, and different standing tasks. They all agree that the WBB provides comparable data to the laboratory force plate, even though there were some differences which were attributed to the sensitivity of the sensors and different signal processing schemes.

Table 3.2: Studies testing the reliability and validity of WBB data for balance assessment

Study	Sample	Aim	Measure	Methods	Validity	Reliability
Clark et al. 2010	n= 30 young adults	Compare COP data from WBB with FP	Total COP path length	2 sessions, 4 balance tasks; EO2L & EC2L for 30 sec, EO1L & EC1L for 10 sec, on both devices, 3 trials on each	Excellent concurrent validity [ICC = 0.77–0.89]. The SEM [FP range=3.5–10, WBB range = 4–11.4] and MDC [FP range = 14.5–34.7%, WBB range = 24.5–29.4%]	Both devices showed excellent test re-test reliability [ICC > 0.75] across balance tasks except EO2L task on WBB [ICC = 0.66].
Chang et al. 2013	n=20 young adults, n=20 older adults	Test reliability and validity of WBB compared to SBM	The average COP length	1 session, 3 balance tasks; EO2L, EC2L, and EO1L, 3 times for 10 sec each on both devices	The correlation between SBM and WBB was significantly positive with high degrees of validity [r > 0.5, and p < 0.05].	The ICC for WBB of the young adults [0.19-0.28] and elderly adults [0.7-0.97]. The ICC for SBM [0.93-0.99] of both groups.
Bower et al. 2014	n=30 post stroke adults	Test reliability of WBB standing balance measures and its correlation with clinical dynamic balance tests [10MWT, TUG, Step Test and FRT]	Total COP velocity {ML & AP}, the WBA, peak force during STS	2 sessions, 5 balance tasks; EO2L & EC2L for 30 sec with one WBB, WBA, dynamic STS and dynamic MLWS for 30 sec with two WBBs, 3 trials for each	COP velocity with EO is the most significant correlation with FR [-0.61], moderate correlation between WBB dynamic MLWS and Step Test and TUG [-0.53, -0.57] No correlations were found between the clinical balance tests and WBA or dynamic STS force variables	Excellent test-retest reliability for WBB parameters [ICC 0.82-0.98]. Bland-Altman plots for WBB variables show no systematic bias or trends between sessions
Park & Lee 2014	n=20 young adults	Test the reliability and validity of WBB and Balancia compared to FP	The COP length and COP velocity	3 sessions. 1st: on WBB with 2 assessors, 2nd: on WBB with 1 assessor, & 3rd: on FP with 1 assessor 4 balance tasks; EO2L & EC2L for 30 sec, EO1L & EC1L for 10 sec repeated thrice.	High concurrent validity with strong correlations for EO2L, EC2L, EO1L and moderate correlation for EC1L. The Bland-Altman plot showed agreement between inter-ratter COP path length scores	Inter-ratter & Intra-ratter reliability showed strong correlations for EO2L & EC2L and moderate correlations for EO1L & EC1L. The Bland-Altman plot showed ‘good’ reliability

Larsen et al. 2014	n=54 children [10-14y]	To investigate the reliability and validity of the WBB when compared to FP for children	COP path length	1 session, 3 trials of 4 tasks: EO2L, EC2L, EO1L dominant, and EO1L non-dominant leg for 30 sec on both the WBB and FP	The concurrent validity was satisfactory [CCC = 0.74-0.87]. The mean difference was highest for EO1L non-dominant leg. Bland-Altman plots showed larger variation in the unilateral tests.	The CCC was ranging from 0.76 to 0.83 for WBB and from 0.79 to 0.86 for FP
Scaglioni-Solano & Argon-Vergas et al. 2014	n=37 older adults	Reliability and validity of WBB to quantify COP motions during mCTSIB tests	COP movement	3 repetitions of 5 balance tasks of mCTSIB; EO2L, EC2L, EO2LFS, EC2LFS, and tandem stance, on both FP and WBB	Excellent concurrent validity Bland-Altman plots show agreement between force platform and WBB	Modest to excellent test-retest reliability [ICC0.64-0.85]. SEM and MDC similar for both devices except EC conditions
Abubajer et al. 2015	n=35 older adults with total joint arthroplasty	Test concurrent validity and reliability of WBB force measurements compared to FP during STS and return STS tasks	Peak VGRF & inter-limb symmetry percentage ratios	2 balance tasks; STS and return STS performed on WBB and FP for 3 sec, 3 trials each.	Excellent agreement between the two methods for peak VGRF[ICC3,3 0.97-0.98] and asymmetry ratio [ICC3,3 0.83-0.88] during STS and return STS tasks	Intra-session reliability assessed using Cronbach's alpha between first and last trials showed excellent agreement for all measures across 3 trials on the WBB [ICC3,1= 0.844-0.995]

10MWT=Ten Meter Walk test, AP=anterior-posterior, CCC=concordance correlation coefficient, COP=centre of pressure, EC1L=standing on one leg with eyes closed, EC2L=double-leg standing with eyes closed, EC2LFS=double-leg standing with eyes closed on a foam surface, EO1L=standing on one leg with eyes open, EO2L=double-leg standing with eyes open, EO2LFS=double-leg standing with eyes open on a foam surface, FP=force plate, FRT=functional reach, ICC=interclass correlation coefficient, mCTSIB=modified Clinical Test of Sensory Integration, MDC=minimum detectable change, ML=mediolateral, MLWS=mediolateral weight shifting, SEM=standard error of measurements, STS=sit to stand, TUG=timed up and go, vGRF=vertical component of the ground reaction force, WBA=weight bearing asymmetry, WBB=Wii balance board

Table 3.3: Studies testing only the validity of WBB's data for balance assessment

Study	Sample	Aim	Measure	Methods	Validity
Holmes et al. 2013b	n=20 Adults with PD	Test the validity of the WBB by comparing it with FP for adults with PD	The COP path length	1 session, 4 balance tasks performed twice for 30 sec on each device; EO2L, EC2L, and same tasks with feet together	Excellent concurrent validity across all balance tasks [ICCs = 0.92–0.98]. Bland–Altman plots showed higher mean COP path length on WBB as compared with FP
Huurnink et al. 2013	n=14 young adults	The WBB was on top of a FP to compare simultaneous COP data during single leg stance.	The COP velocity and mean sway	1 session, 10 trials of 3 balance tasks for 10 sec each: EO1L, EC1L and single-leg stance after a short sideways hop.	The FP and WBB were highly correlated [r>0.996]. The COP trajectories measured during the three balance tasks were similar for FP and WBB systems
Yamamoto & Matsuzawa 2013	n=10 young adults	Test validity of vGRF from WBB during jumping compared to FP	The vGRF curve	The WBB was on top of FP, 1 session, 2 jump trials on WBB	Strong and statistically significant linear correlation [r = 0.99] between both devices when assessing jumping force but not in landings [strong shocks]
Pavan et al. 2015	n=28 young adults	The WBB was on top of a FP to compare simultaneous measurements of COP sway	The COP path and AP and ML max sway	1 session, 2 tasks repeated twice for 30 sec; EO2L and EC2L.	The error between WBB and FP for all measures was [3%-5%]. Bland–Altman agreement between two signals from WBB on top of FP.
Sgro et al. 2014	n=10 young adults	Assess validity of WBB versus BP in normal standing	Total COP path length	2 balance tasks; EO2L and EC2L on WBB and BP for 25 sec	Bland Altman plots showed good agreement between WBB and BP and the ICC values were; EO2L {ICC2,1= 0.79}, EC2L {ICC2,1= 0.83}

AP=anterior-posterior, BP=baropodometer platform, COP=centre of pressure, EC1L=standing on one leg with eyes closed, EC2L=double-leg standing with eyes closed, EO1L=standing on one leg with eyes open, EO2L=double-leg standing with eyes open, FP=force plate, ICC=interclass correlation coefficient, ML=mediolateral, PD=Parkinson's disease, vGRF=vertical component of the ground reaction force, WBB=Wii balance board

Table 3.4: Studies testing only the reliability of WBB's data for balance assessment

Study	Sample	Aim	Measure	Methods	Reliability
Clark et al. 2011	n=23 young adults	Test reliability of WBA using two WBBs during squatting	Mean WBA and COP path velocity for each limb	2 sessions, 5 continuous squatting trials, with each foot on a separate WBB [6 sec each], with and without visual feedback	Both WBA and COP path velocity assessed with and without feedback showed excellent reliability [ICC≥0.75].
Jeter et al. 2015	n=14 blinded adults & n= 21 adults with normal vision	Assess intra-session reliability of WBB with visually impaired adults	COP length, COP velocity and COP structure [Approximate Entropy in AP & ML]	One session, 2 testing, 4 balance tasks; EO2L, EC2L, EO2LFS, EC2LFS for 30 sec, 3 trials for each task.	The COP parameters increased with difficulty of balance task highlighting sensitivity of the WBB [p<0.01]. The WBB is reliable when assessing balance in blinded adults [ICC=0.73-0.95] and adults with normal vision [ICC=0.62-0.94]

AP=anterior-posterior, COP=centre of pressure, EC2L=double-leg standing with eyes closed, EC2LFS=double-leg standing with eyes closed on a foam surface, EO2L=double-leg standing with eyes open, EO2LFS=double-leg standing with eyes open on a foam surface, ICC=interclass correlation coefficient, WBA=weight bearing asymmetry, WBB=Wii balance board

3.3.2 The usability of the WBB COP data

The high technology of the WBB in detecting COP movement while standing has been shown to be valid and reliable. However, other researchers have looked at other ways of using the WWB technology. Four studies were found in literature that discussed the ability of WBB's COP data to inform clinicians and researchers outcomes other than balance. These studies used the COP parameters detected by the WBB to address different therapeutic purposes, such as; predicting falls (Kwok et al. 2015), predicting the suitable walking aid (Pua et al. 2015), assessing sleepiness (Tietäväinen et al. 2013), and detecting postural changes with different visual tasks (Koslucher et al. 2012).

Koslucher et al. (2012) tested the WBB's sensitivity to the effects of visual tasks when measuring standing sway in ten older adults. The aim of this study was to determine the ability of the WBB to reliably detect postural changes associated with different visual tasks. Subjects were asked to stand on the WBB and perform six trials; three involved an inspection task and other three trials involved a search task. A blank white card was fixed on the wall for the inspection task, and a card with a paragraph of English text was also fixed on the wall for the search task. For the search task, the participants were instructed to read the text and count the number of targeted letters in the text. The assessment was based on the magnitude of postural variability of the COP movements in the AP and ML axes for each task and trial. The results showed a significant reduction in positional variability of the COP in the AP axis during the search task as compared to the inspection task [$p = 0.022$] (Koslucher et al. 2012). The search task require more attention than the inspection task, this may indicate that participants had better control while focusing on cognitive challenging task. This study was the first to show the effect of visual tasks on the postural sway dynamics among the elderly. However, the sample size was small to generalize the findings to a larger population. In addition, the study findings can only be applied to older adults who have different postural control mechanisms than other populations.

Tieavainen et al. (2013) investigated the ability of WBB to detect sleepiness in 15 young adults. Postural steadiness was measured with the WBB every hour for 24 h and participants were asked to wake up 1.5 h before the first measurement. They were asked to stand on the WBB for 30 sec with eyes open four times for each measurement. The complexity index is a sway measure that describes the regularity of the COP signals. The results showed a significant decrease in the complexity index during the 24 h of time awake [$p < 0.001$], which is associated with impaired postural steadiness. The complexity index group average was 8.9 ±1.3 for alert subjects and 7.9 ± 1.4 for sleepy subjects [$p<0.001$]. The correlation between the complexity index and the alertness estimation was 0.94. Therefore, the WBB can detect impairment in postural steadiness due to staying 24 h time awake, when using the complexity index to quantify sleepiness (Tietäväinen et al. 2013). Although the sample was composed of younger adults, the study findings agree with Koslucher et al. (2012) that attention is related to postural control. In this study, the participants demonstrated higher COP irregularity when they were the most sleepy, which means their ability to pay attention was decreased. Although neither study aimed to test the reliability or validity of the outcome measures used, they confirmed the usability of the WBB to evaluate and differentiate postural control according to visual tasks or alertness.

Kwok et al. (2015) claim that COP data from the WBB could predict future falls among community-dwelling older adults. Standing balance was measured for 73 participant who are aged between 60 and 85 years. These clinical and laboratory measures included the COP sway velocity measured using the WBB. Over a one year period, follow up reports of falling incidences were collected. The results showed 25% of the sample reported a fall in the past year. There was no statistical difference between the balance measurements of the non-fallers and fallers groups except for the WBB's COP sway velocity. The most precise prediction of falls is the COP velocity in the AP direction; as the COP velocity in the AP direction increases, the odds ratio of falling increases (Kwok et al. 2015). However, the number of fallers was significantly lower than the number of non-fallers, which may have affected the statistical testing.

Pua et al. (2015) designed a prediction model of eight predictors of suitable types of walking aids for 89 inpatients following total knee arthroplasty. The four walking aids used in this study were walking sticks, narrow-based quad sticks, wide-based quad sticks and walking frames. One of the eight predictors was the COP movement in the ML direction while standing on the WBB. The results showed that three main predictors were significant in predicting the type of walking aid—sex, BMI and COP ML sway. The higher these predictors, the more likely that a patient will require a larger walking aid. The mean COP ML for each walking aid group was: walking stick [0.26 cm], narrow-based quad stick [0.31 cm], wide-based quad stick [0.34] and walking frame [0.44 cm]. Therefore, the COP sway in the ML direction collected from the WBB can be used to classify patients according to the walking aid required. This could assist clinicians in prescribing the appropriate type of walking aids for patients following total knee arthroplasty (Pua et al. 2015). Although the sample size was large enough to make such conclusions, it might be hard to generalize these results to different patient populations. The sample consisted of patients who had recently had knee surgery, which affects the standing postural control mechanism; other surgeries on the hip or ankle joints might affect the standing mechanism differently.

3.3.3 The Wii-Fit balance test with WBB

As mentioned earlier, Wii Fit is fitness game with many different exercises, including aerobic, strengthening, yoga and balance exercises. Wii Fit features a body test that is usually conducted prior to playing the game and that measures the player’s weight, BMI balance and calculates the Wii Fit age. All this data is saved for each character/player on the secure digital card to enable the players to monitor their fitness progression.

The Wii Fit body test also contains a balance test called the ‘Centre of Balance’ [COB] test, which gives visual feedback about the location of the player’s COP and percentage of weight distribution on each side. When an individual stands on the WBB, the screen will show an outline of the WBB, with a moving red dot representing the individual’s COP movement. This test takes 20 sec after which a COB score, which is a percentage of weight on each side, is shown on the screen as an indicator of the right-left symmetry.

The right-left symmetry outcome may be beneficial because it provides feedback during balance training. However, it does not measure the amount of sway or represent the sway direction either forward or backward. For example, an individual could show a good right-left symmetry without showing a quantitative value because their weight distribution could be in a more forward or backward direction. Furthermore, this test was designed to provide a general level of balance in a healthy population. The major challenge is to understand how the COB score is determined in research or clinical settings for different populations, and whether this score is a reliable and valid outcome for measuring balance.

It should be clarified that the balance data from the WBB that is measured using a computer software is different from the Wii Fit balance test score that is taken from the WBB. The WBB communicates with the chosen software to yield data on each sensor where the parameters of the COP can be calculated. This WBB data has been shown to be a valid measure of balance and is comparable to the force plate measures (Clark et al. 2010). However, when the WBB communicates with the Wii Fit game software for testing balance, the data cannot be used to calculate the COP parameters because it does not provide the COP coordinate values. Some researchers have confused the balance data from the WBB and the balance test score provided by Wii Fit through the WBB. Consequently, following the results of Clark et al. (2010), some researchers have considered the Wii Fit balance test to be an outcome measure of balance.

3.3.4 The validity and reliability of Wii Fit balance games scores and tests

Clark et al. (2010) assumed that the results obtained using the Nintendo Wii, including the Wii-Fit balance test, could provide valid and sufficient results (Clark et al. 2010). However, this assumption was based on their results and was not tested. Gras et al. (2009) and Wikstrom (2012) tested the validity and reliability of the Wii Fit balance test and balance games scores, respectively.

Gras et al. (2009) compared the reliability and concurrent validity of the Wii-Fit balance test with that of the NeuroCom EquiTest. Participants were asked to complete the COB test on the Wii Fit for 20 sec, followed by the NeuroCom EquiTest for 30 sec, which mimicked the COB test for measuring right-left symmetry. The study results showed that the COB score was unreliable [ICC = 0.253]; however, there was a correlation between the Wii Fit and the NeuroCom EquiTest [$r = 0.532$; $p = 0.001$] in terms of right-left symmetry. Despite this correlation, the measurements were not reliable. Therefore, Gras et al. (2009) concluded that the Wii Fit balance test was neither accurate nor consistent when compared to the NeuroCom EquiTest. This may be owing to the fact that both instruments were designed differently; the NeuroCom EquiTest uses a dynamic force plate, whereas the WBB uses a static force plate. To truly test the validity of the Wii Fit balance test data, it should be compared with the measurement data of a laboratory force plate. However, the Wii Fit COB score has been shown to be unreliable (Gras et al. 2009). Moreover, it provides only one outcome measure, that is, the right-left symmetry.

Besides the Wii Fit balance test, the Wii Fit balance game scores were also used by some researchers as an outcome measure of balance. However, the game score usually refers to the targets met by the player in each game and does not refer to the player's balance performance. Wikstrom (2012) tested the concurrent validity and reliability and the intra-session and inter-session reliability of the Wii Fit balance game scores. A total of 45 young adults completed two test sessions with a one-week break in between. The first test session included unilateral standing on a test force plate to measure the COP sway excursions, the Star Excursion Balance Test [SEBT] to measure reaching distance, which is a reliable measure of dynamic balance, and some Wii Fit activities. In the second session, 12 Wii Fit activities with various unilateral and bilateral standing tasks were completed. The Wii Fit balance activity scores and the established balance task outcomes were found to be poorly correlated [$r < 0.50$]. This means that the concurrent validity was not established. Moreover, the Wii Fit balance activity scores demonstrated poor inter-session reliability with high minimum detectable change [MDC] scores. Wikstrom (2012) concluded that Wii Fit balance activity scores should not be used as an objective outcome measure or for monitoring the progress of balance during rehabilitation. However, using Wii or Wii Fit in a clinical setting was recommended.

In addition, improvements in the game scores were sometimes interpreted as the effect of Wii fit training. However, this effect was not transferred to performance on the other balance gaming device, according to the results of Naumann et al. (2015). This study divided 37 healthy young adults into three groups: 12 in a Nintendo Wii Fit group, 12 in an MFT Challenge Disc group and 13 in a control group. Participants in both intervention groups were trained for 30 min per session, three sessions a week for four weeks. Four balance games were selected for each group from each game system. These games were similar in terms of their weight shifting requirements; however, the Wii Fit games were played using the WBB, which is a stable platform, while the MFT Challenge Disc games use a movable platform. The game scores from each deceive were the main dependent measures, with the COP measurement obtained using an force plate. The results revealed that participants who played Wii Fit games showed significantly higher game scores than when playing MFT Challenge Disc games, and participants who played MFT Challenge Disc games showed significantly higher game scores than when playing Wii Fit games. This means that each group performed better on their games that were trained with and did not perform well on different games. This pattern shows that the balance effect revealed by the game scores is highly specific to the gaming device (Naumann et al. 2015). Therefore, the games scores are not good indicators of balance improvement and does not reflect an effect of training because they are mainly calculated based on time.

Reed-Jones et al. (2012b) evaluated the correlation between Wii Fit balance tests and clinical functional standardized tests of balance, mobility and fitness among 34 older adults with a mean age of 67.1±5.2 years. The functional tests were a combination of muscular strength tests with a grip strength dynamometer, muscular endurance using the 30 sec chair stand and 30 sec arm curl tests, cardiovascular endurance with the 6MWT, functional mobility with an obstacle course, dynamic balance with the TUG test, and self-reported balance confidence with the Activities specific Balance Confidence scale [ABCS]. The results showed no significant correlations between the Wii Fit tests and any of the functional tests, suggesting that balance test scores on the Wii Fit are not predictors for any of the functional test performances (Reed-Jones et al. 2012b). However, almost all functional tests are of a different nature than the Wii Fit balance test. For example, the TUG test and the obstacle course are dynamic in nature and require different balance skills than the static standing balance skills required for the Wii Fit tests, whereas static balance tests such as single-leg stance with eyes open and closed may reveal different correlations with the Wii Fit tests. The results of Reed-Jones et al. (2012b) agree with those of previous studies that concluded Wii Fit tests are not recommended for balance assessments.

It can therefore be concluded that Wii Fit games or tests scores are not recommended for balance assessment due to their lack of reliability and validity outcomes. In addition, the improvement in games scores are highly specific to the Wii Fit, the effects do not transfer to other similar games. Furthermore, the Wii Fit balance tests do not correlate with any functional tests of balance, fitness or mobility. These findings highlighted the importance of taking care when interpreting results based on Wii Fit test or game scores. However, the WBB is an independent assessment tool because it can communicate with different software to calculate COP parameters to measure balance.

3.4 Wii Fit games as balance intervention tool

Physiotherapists have begun using Wii games in their treatment sessions (DiMola 2009), during which patients can enjoy the game and focus on a certain therapeutic movement. However, the evidence behind its effectiveness in balance training is still limited. A literature search revealed 52 studies that have investigated the effect of Wii Fit games on balance training. This section includes all studies which were conducted with both adult and child populations. The adult population included; older adults, adults after musculoskeletal surgeries, adults with stroke, adults with PD, adults with traumatic brain injury [TBI], and adults with vestibular loss. The child population included; children with poor balance due to different diagnoses, such as developmental coordination disorder [DCD], Down syndrome [DS], developmental delay, lower limb amputation, TBI, migraine without aura [MoA], and CP. For each population, a group of studies are discussed based on the study design, the Wii Fit training duration and type of games, the outcome measures used and the main findings.

3.4.1 Adult population

3.4.1.1 Older adults

Ensuring improved balance for the elderly is a major concern because they are likely to be more unstable and at a higher risk of falling than younger adults. Numerous researchers have focused on investigating the effect of balance training on preventing falls and increasing confidence among the elderly, besides studying balance interventions ranging from using sophisticated lab equipment to home exercises. Despite this, few studies have been conducted to investigate the effectiveness of the use of Wii Fit as an intervention for improving balance among community-dwelling older adults (Williams et al. 2010; Bainbridge et al. 2011; Williams et al. 2011; Pluchino et al. 2012; Rendon et al. 2012; Singh et al. 2012; Toulotte et al. 2012; Reed-Jones et al. 2012a; Bieryla & Dold 2013; Singh et al. 2013; Cho et al. 2014), older adults undergoing physiotherapy training (Bateni 2012; Laver et al. 2012), and older adults living in assisted living residences (Padala et al. 2012; Chao et al. 2013). Table 3.5 presents the details of the 15 studies that have tested the effectiveness of Wii fit balance training among older adults.

3.4.1.1.1 Study design

Of the 15 studies found in the literature, only two are RCTs (Pluchino et al. 2012; Toulotte et al. 2012). Most are feasibility or pilot studies; 10 are controlled pre- and post-test studies (Williams et al. 2010; Bateni 2012; Laver et al. 2012; Padala et al. 2012; Rendon et al. 2012; Singh et al. 2012; Reed-Jones et al. 2012a; Bieryla & Dold 2013; Singh et al. 2013; Cho et al. 2014) and three are pre-and post-test studies without control groups (Bainbridge et al. 2011; Young et al. 2011; Chao et al. 2013).

The sample size of all the studies was considerably small, ranging from eight participants to 45 participants. This has limited the generalizability of the results to the wider population. Additionally, most of the studies used unpowered samples, except that conducted by Pluchino et al. (2012) where the original sample consisted of 40 participants. However, the sample decreased to 27 participants due to a high dropout rate. Some studies were conducted on nonhomogeneous samples where there were more females than males, with only one male in each group (Bainbridge et al. 2011; Williams et al. 2011; Bieryla & Dold 2013), or the whole sample consisted of females (Singh et al. 2012; Singh et al. 2013). This is not an adequate representation of the older adult population.

Although 10 studies randomly divided participants into groups (Laver et al. 2012; Padala et al. 2012; Pluchino et al. 2012; Rendon et al. 2012; Singh et al. 2012; Toulotte et al. 2012; Reed-Jones et al. 2012a; Bieryla & Dold 2013; Singh et al. 2013; Cho et al. 2014), only four mentioned how that randomisation was conducted (Laver et al. 2012; Padala et al. 2012; Pluchino et al. 2012; Toulotte et al. 2012). The sample used in Williams et al. (2010) was not randomised, and there was a significant difference in the characteristics of the groups at baseline. Additionally, the intervention group was recruited from within the community, whereas the standard care group was recruited from among participants of a local falls programme. Participants were recruited in a similar manner in Bateni (2012), in which two groups of patients who had limited balance ability and were undertaking physiotherapy treatment were compared to one group of healthy individuals who were carrying out normal daily activities. It is possible that this baseline imbalance affected the outcome of the study. Furthermore, the absence of a control group, which shows the true effect of the intervention, does not demonstrate adequate evidence of the effectiveness of Wii Fit in improving balance (Bainbridge et al. 2011; Williams et al. 2011).

3.4.1.1.2 Wii Fit training

The Wii Fit training used in all studies was based on a selection of balance games only (Bateni 2012; Pluchino et al. 2012; Rendon et al. 2012; Singh et al. 2012; Singh et al. 2013; Cho et al. 2014) or with other games like yoga and aerobics games (Williams et al. 2010; Bainbridge et al. 2011; Williams et al. 2011; Laver et al. 2012; Padala et al. 2012; Toulotte et al. 2012; Bieryla & Dold 2013; Chao et al. 2013). The training duration varied across studies from a short duration of three to four weeks (Williams et al. 2011; Bateni 2012; Bieryla & Dold 2013) to a long duration of 12 to 20 weeks (Williams et al. 2010; Toulotte et al. 2012;

Reed-Jones et al. 2012a). However, almost half of the studies selected a Wii Fit training duration of six to eight weeks (Bainbridge et al. 2011; Padala et al. 2012; Pluchino et al. 2012; Rendon et al. 2012; Singh et al. 2012; Chao et al. 2013; Singh et al. 2013; Cho et al. 2014). Although it can be argued that a short duration might not be enough to show significant changes, a long duration like 20 weeks (Toulotte et al. 2012) may have caused a gap between the pre- and post-assessments. Furthermore, it may have showed the long-term effect rather than the immediate effect.

The timing of training sessions and the number of sessions per week also varied across studies, ranging from 20 min to one hour and from once a week to three sessions a week, respectively. However, a long training session, such as one hour (Toulotte et al. 2012), may not be practical for a rehabilitation clinic and may be too long for an older population. Regardless of how long Wii Fit training was or how many sessions, most studies have shown significant balance improvements after training when assessed using laboratory or clinical measures. In addition, participants showed a high level of adherence to Wii Fit balance training.

3.4.1.1.3 Outcome measures

The outcome measures used in most studies investigating the effectiveness of Wii fit balance training were either clinical functional measures to assess balance performance, laboratory equipment to detect COP parameters during standing or a combination of both. The laboratory equipment used was either to assess static standing balance with force plates (Pluchino et al. 2012; Singh et al. 2013; Cho et al. 2014) or dynamic balance with dynamic motion analysis systems (Pluchino et al. 2012). Although COP parameters during standing are objective measures, functional clinical measures can give an idea if the difference in COP movements is clinically or functionally meaningful when performing a dynamic balance task. Therefore, using both clinical measures and laboratory outcomes (Pluchino et al. 2012; Singh et al. 2013) is more favourable than using just one.

The most clinical measures used were the TUG (Laver et al. 2012; Padala et al. 2012; Pluchino et al. 2012; Rendon et al. 2012; Reed-Jones et al. 2012a; Bieryla & Dold 2013; Chao et al. 2013; Singh et al. 2013), Berg Balance Scale [BBS] (Williams et al. 2010; Bainbridge et al. 2011; Williams et al. 2011; Bateni 2012; Laver et al. 2012; Padala et al. 2012; Bieryla & Dold 2013; Chao et al. 2013), Tinetti test (Williams et al. 2010; Padala et al. 2012; Pluchino et al. 2012; Toulotte et al. 2012), the FRT (Pluchino et al. 2012; Reed-Jones et al. 2012a; Bieryla & Dold 2013), and Single Leg Stance [SLS] (Pluchino et al. 2012; Toulotte et al. 2012). These clinical tools have shown good psychometric properties of validity and reliability for the same population. However, most of the measures are subjective and can be affected by ratter bias, especially if the assessor was not blinded to group allocation or training. Of all the studies that used clinical measures, only one ensured the assessor was blinded (Singh et al. 2013).

Some studies used outcome measures not designed to assess balance or did not provide reliable or valid data. For example, Williams et al. (2010) used the Wii Fit age, which reflects the players' overall fitness level; this cannot be considered a balance measure. The Wii Fit balance test was considered a quantitative COP excursion measurement (Bainbridge et al. 2011; Toulotte et al. 2012), although this test is not reliable or valid, according to the results of Gras et al. (2009). Furthermore, one of the Wii Fit games, the 'Balance Bubble' game, where players have to maintain postural control while moving in a bubble, was used as an outcome measure in Bateni (2012). However, the game scores of Wii Fit games have been shown to be an unreliable assessment of balance (Wikstrom 2012). Reed-Jones et al. (2012a) designed an obstacle course that was assessed based on time of completion and number of obstacles hits as outcome measures of fall prevention. This kind of assessment resembles real life obstacles for older adults with a fear of falling. Although this measure is not a clinical balance measure, it was found to be highly correlated with the TUG and FRT tests. However, the reliability and validity of this test need to be investigated further.

3.4.1.1.4 Results

Most studies concluded that Wii Fit training is safe, enjoyable and acceptable among adults. In addition, Wii Fit training increase confidence in balance and decrease fear of falling, which was assessed by self-rating questionnaires (Williams et al. 2010; Bainbridge et al. 2011; Laver et al. 2012; Pluchino et al. 2012; Rendon et al. 2012; Singh et al. 2012; Chao et al. 2013).

The effect of Wii Fit balance training alone was tested with one group pre- & post-test of analysis (Bainbridge et al. 2011; Williams et al. 2011; Chao et al. 2013). These studies demonstrated a positive effect of training presented in an increase BBS score after training, however this improvement was statistically significant in only two studies (Williams et al. 2011; Chao et al. 2013).

Other studies compared the effect of Wii Fit training to no training at all (Rendon et al. 2012; Bieryla & Dold 2013; Cho et al. 2014) and showed significant improvements in TUG and ABCS scores (Rendon et al. 2012) and a significant decrease of COP area during standing (Cho et al. 2014) in the Wii Fit group. Bieryla and Dold (2013) did not find significant changes in the TUG, FRT or Fullerton Advanced Balance [FAB] scale scores; however, participants in the Wii fit group showed a significant increase in BBS scores at the one-month follow-up assessment. Thus, this improvement was not seen after three weeks of training, which means it was not an effect of training but may be due to activities performed during the follow-up period.

Nine studies investigated the effect of Wii Fit training in comparison to other forms of balance training like fall care programmes (Williams et al. 2010), tai chi (Pluchino et al. 2012), physical activity (Toulotte et al. 2012), agility exercises (Reed-Jones et al. 2012a), walking (Padala et al. 2012), physiotherapy (Bateni 2012; Laver et al. 2012) and balance exercises (Pluchino et al. 2012; Singh et al. 2012; Singh et al. 2013). Four studies showed no significant difference between groups, indicating that Wii Fit balance training is equal to balance exercises. However, all have shown significant improvements after training in static and dynamic balance assessed by the TUG test, the Ten Step test, the postural sway index (Singh et al. 2013), the BBS and the Tinetti test (Padala et al. 2012); the level of confidence assessed by ABCS (Singh et al. 2012) and dynamic balance reactions assessed by a dynamic motion analysis system (Pluchino et al. 2012). This means that Wii Fit training is not superior to any other form of balance training and may have the same effect. At the same time, it did show effective results after training.

The other five studies found differences between groups; however, three of them did not compare Wii Fit training to balance exercises. For example, Williams et al. (2010) compared Wii Fit balance training, which consists of active exercise, to a local standard care fall programme that consists of education and exercise and showed significant changes in BBS for the Wii Fit group. Although this difference shows a positive effect of Wii Fit training, it may not be rigorous enough due to differences between groups in baseline and in type of training given. All participants in the study by Reed-Jones et al. (2012a) were trained with strengthening, cardiovascular and balance exercises, but the difference in groups was in 15 min extra training in the form of agility exercises or Wii Fit training. All groups showed improvements after training, however. The Wii Fit group had the greatest overall improvement in the obstacle course. Although caution must be taken when interpreting this finding, this shows the effect of visual weight shifting training and the cognitive training of the games on older adults to prevent falls. Toulotte et al. (2012) compared Wii Fit balance training to a physical activity programme and concluded that a combination of Wii Fit balance training and physical activity might produce better results in terms of improving balance than using Wii Fit balance training alone. This was reflected in the significant changes in the Tinetti test {static and dynamic} and the unipedal test {eyes open and eyes closed} of the Wii Fit and physical activity groups. The Wii Fit group showed significant changes in the static part of the Tinetti test only.

Only two studies compared Wii Fit training to physiotherapy and found significant differences between groups (Bateni 2012; Laver et al. 2012). Bateni (2012) agreed with Toulotte et al. (2012) that combining the Wii Fit games with other forms of training provide better results than Wii Fit training alone. The results showed a significant increase in BBS scores after training for the Wii Fit plus physiotherapy group and the physiotherapy group (Bateni 2012). This may be because physiotherapy exercises can be more flexible and customised to a patient's needs, whereas Wii Fit games are the opposite. Additionally, as mentioned earlier, the Wii Fit group had a higher BBS score than other groups at baseline because they do not receive physiotherapy and are independent healthy elderly. Laver et al. (2012) investigated the effect of Wii Fit games on hospitalized older adults recruited from a geriatric rehabilitation unit. The Wii Fit group demonstrated significant improvements in TUG and BBS scores in comparison to the conventional rehabilitation group (Laver et al. 2012). As the sample is composed of older adults who are in a rehabilitation programme, the improvement seen in the Wii Fit group may be because it was a plus training to the conventional rehabilitation. Therefore, this result agrees with previous studies (Bateni 2012; Toulotte et al. 2012) that Wii Fit games alone may not be enough to bring about clinical changes, but when including them with other forms of training, they do give significant results.

Table 3.5: Studies that tested the effect of Wii Fit balance games on older adults

Study	Sample	Groups	Wii Fit training	Assessment	Results
Williams et al 2010	n=21 Community dwelling fallers over 70 y/o	2 groups; 1- Wii Fit {n=15} 2- Standard care, falls program {n=6}	2/week for 12 weeks 4 Balance games, 3 aerobic games & 1 Yoga game	Before training, at week 4 & at week 12 with; BBS, TT, FES-I, AFRIS, Wii Fit age only for Wii Fit group	Significant improvement in BBS at 4 weeks only. Significant difference in Wii Fit age after 12 weeks. Standard care group show significant increase in FES. No significant difference between groups at other measures.
Bainbridge et al 2011	n=8 Community dwelling older adults aged above 65 y/o	One group	30 min, 2/week for 6 weeks 4 balance games & Yoga	Before and after training with; BBS, ABCS, MDRT,COP excursion {Wii Fit COB test}	Improvement in BBS, ABCS & MDRT for 3-4 out of 6 participants, but it was not significant
Williams et al 2011	n=22 older adults aged 74-94 y/o	One group	20 min, 3/week for 4 weeks {balance & aerobics games}	Before & after training with; BBS	Significant improvement in BBS [$p < 0.01$]
Bateni 2011	n=18 Older adults from PT clinic & community aged 53-91 y/o	3 groups; 1- PT+ Wii Fit {n= 5} 2- PT {n=6} 3- Wii Fit {n=6} from community.	3/week for 4 week 3 balance games	Before, mid [week 2], & after 4 weeks with; BBS & Bubble test scores [for PTW & Wii groups]	All groups improved, PT & PTW groups show better improvement in BBS than Wii group, and PTW group show higher scores in bubble test than Wii group
Rendon et al 2012	n= 34 Older adults aged between 60 & 95 y/o	2 groups; 1- Wii Fit {n=16} 2- Control, no training {n=18}	35-45 min, 3/week for 6 weeks. 3 balance games	Before & after training with; 8-foot Up & Go, ABCS, & GDS	Significant improvements in 8-foot Up & Go & ABCS for the Wii Fit group after training, compared to control group

Pluchino et al 2012	n=40 Independent seniors mean age 72.5 ± 8.4 y/o	3 groups 1- Wii Fit {n=8} 2- Balance exercise{n=8} 3- Tai Chi {n=11}	60 min, 2/week for 8 weeks 9 balance games	Before & after training with; TUG, SLS, FRT, TT, force plate {COP}, DMA, FROP-Com, & FES	No significant difference between groups of all measures. Significant increase in COP measures & significant decrease in DMA after training for all groups
Singh et al 2012	n=36 community dwelling women aged above 56 y/o	2 groups {n=18 each}; 1- Wii fit group 2- Balance program group	40 min, 2/week for 6 weeks 5 balance games	Before &after training with; PPA & ABCS	No significant difference between groups. Significant improvements after training in both groups
Toulotte et al 2012	n=36 Healthy elderly with history of fall and mean age 75 y/o	4 groups {n=9 in each group}; 1- G1 PA 2- G2 Wii Fit 3- G3 Wii Fit & PA 4- G4 control	1 hour/ week, for 20 weeks. 5 balance games & Yoga	Before & after training with; TT, Wii Fit test {COB test}, & Unipedal test with eye open then with eye close	G1&G3 show significant balance improvement in all outcome measures, except Wii Fit test, only G3 show significant difference. G2 show significant decrease in TT static scores only
Reed-jones et al 2012a	n=45 older adults with mean age 67.5± 5.9 y/o	3 groups {n=15 each}; 1- G1 control 2- G2 Agility 3- G3 Visual [Wii Fit]	90 min, 2/week for 12 weeks. Strengthening, cardiovascular & balance exercises for all groups. Plus agility or Wii Fit for G2 & G3	Before, mid {week 6} & after training {week 12} with; 10 fitness tests, obstacle course measures [number of hits and time of completion]	Significant improvements in all fitness test & completion time for all groups. G3 showed significant decrease in number of hits at mid assessment only. G3 had the greatest overall improvement of 22%.
Padala et al 2012	n=22 Older adults with mild Alzheimer's dementia from ALR aged above 60 y/o	2 groups {n=11 each}; 1- Wii Fit group 2- Walking group	30 min, 5/week for 8 weeks. 6 balance games, 4 Yoga games, 3 strength games	Before and after training with; BBS, TT, TUG, ADL, IADL, QOL-ADL, MMSE	No significant difference between groups in all measures. Both groups improved significantly in BBS. Significant improvement after training in BBS & TT in Wii Fit group, and TT & QOL-ADL in the walking group

Laver et al 2012	n= 44 Hospitalised older adults aged 85± 4.5 y/o	2 groups {n=22 each}; 1- Wii Fit 2- PT	25 min, 5/week until discharge Balance , strengthening & aerobic games	Before & after training with; TUG, SPPB, BBS,TIADL, FIM, ABCS	Only Wii fit group showed significant improvement per session in TUG & BBS when compared to PT group
Singh et al 2013	n=36 Senior Malaysian women aged above 56 years	2 groups {n=18 each}; 1- Balance exercises 2- Wii Fit games	30 min, 2/week for 6 weeks 7 balance games	Before & after training by a blinded assessor with; TST, TUG and postural sway [OPI]	Significant improvement in both groups in the OPI & TST , and the TUG No significant differences between the groups.
Bieryla & Dold 2013	n=10 Healthy older adults aged above 70 y/o	2 groups {n=5 each}; 1- Wii fit group 2- Control group, no training	30 min, 3/week for 3 weeks 2 balance games, 1 aerobic game & 3 Yoga games	Before & after training, and 1 month follow up with; BBS, FAB, FRT, TUG	Significant increase in BBS for Wii Fit group after 1 month follow up, but not significant after training. Both groups show no significant improvements in FAB, FRT, TUG
Chao et al 2013	n=7 Older adults from ALR with mean age 86 ± 5 y/o	One group [1 with stroke, 2 with PD, & 1 with COPD]	30 min, 2/week for 8 weeks. 2 balance games, 1 Aerobic game, 1 strength game, 2 Yoga games	Before & after training with; BBS, TUG, 6MWT, FES, SEE, OEE	Significant improvement in only BBS after training
Cho et al 2014	n=32 Healthy elderly aged between 65 and 80 y/o	2 groups; 1- Wii Fit {n=17} 2- Control {n=15}, no training	30 min,3/week for 8 weeks 3 games	Before and after training with; COP area [eyes open & eyes closed]	Significant decrease of COP area after training in the Wii fit group

6MWT= Six min walking test, ABCS= Activities-specific balance confidence scale, ADL= Activities of Daily Living, AFRIS= Attitude to falls related interventions scale, ALR= Assisted Living Residents, BBS= Berg Balance Scale, COB= centre of balance, COP= centre of pressure, COPD= Chronic Obstructive Pulmonary disease, DMA= Dynamic Motion Analysis, FAB= Fullerton Advanced Balance scale, FES= Falls efficacy scale, FIM= Functional Independent measure, FRT= Functional Reach test, FROP-Com= Falls Risk for Older People-Community setting, GDS= Geriatric Depression Scale, IADL= Instrumental Activities of Daily Living, MDRT= Multi-directional reach test, MMSE= Mini Mental State Examination, OEE= Outcome Expectations for Exercise scale, OPI= overall performance index, PA= Physical Activities, PD= Parkinson's disease, PPA= Physiological Profile Approach, QOL-AD= Quality of Life-AD, SEE= Self Efficacy for Exercise scale, SLS= Single Leg Stance test, SPPB= Short Physical Performance Battery, TIADL= Timed Instrumental activities of daily living, TST= Ten Step Test, TT= Tinetti Test, TUG= Timed Up and Go

3.4.1.2 Adults after Knee surgeries

Four studies were found in the literature (Table 3.6) which used the Wii Fit games as a form of rehabilitation for adults following some knee surgeries like total knee replacement (Fung et al. 2012), anterior cruciate ligament reconstruction (Baltaci et al. 2013), posterior cruciate ligament reconstruction (Puh et al. 2014), and adults with history of lower limb injury (Sims et al. 2013). All studies aimed to increase knee joint ROM, muscle strength, and proprioception sense, along with balance during standing either on single or double leg.

Three studies were designed as RCTs (Fung et al. 2012; Baltaci et al. 2013; Sims et al. 2013), and one was a case study (Puh et al. 2014). The sample size in the studies ranged between 28 and 50 participants, and only one study had a power calculation of the sample (Baltaci et al. 2013). In each of the three RCT studies, the sample was divided randomly into two groups of either Wii Fit or lower limb exercises (Fung et al. 2012), conventional rehabilitation (Baltaci et al. 2013) and balance exercises (Sims et al. 2013). However, only Sims et al. (2013) had a third control group of no training. The randomisation process has been demonstrated in all the studies. Most studies had the assessments at baseline, mid training and after training. However, only one study conducted an assessment after every two weeks of training (Fung et al. 2012). Two studies ensured the assessor was blinded to the group allocation (Fung et al. 2012; Sims et al. 2013), while one ensure blinding of both the assessor and the researcher to avoid response bias (Baltaci et al. 2013).

The Wii Fit training involved balance in yoga and aerobics games (Fung et al. 2012; Sims et al. 2013; Puh et al. 2014). Only Baltaci et al. (2013) mixed Wii Fit balance games with Wii Sports games; however, there were no further details about the type of games used. The training duration was four weeks (Sims et al. 2013; Puh et al. 2014), six weeks (Fung et al. 2012) and 12 weeks (Baltaci et al. 2013). The intensity of training was either as limited as 15 min a session twice a week (Fung et al. 2012) or three days a week (Sims et al. 2013) or as much as 45 to 60 min a session three times a week (Baltaci et al. 2013) or six days per week (Puh et al. 2014). These variances in the intensity of training depend on whether there was additional conventional rehabilitation. For example, participants in the Fung et al. (2012) study undertook an extra 60 min of physiotherapy; therefore, the Wii Fit training was only for 15 min. In the study by Baltaci et al. (2013), the Wii Fit training was for one hour as it was compared to the conventional rehabilitation, so there was no extra therapy.

The outcome measures used in most of the studies focused on active ROM, muscle strength, coordination, proprioception and lower limb circumferences. However, all postural outcomes of COP were collected through laboratory systems, including force platforms. These assessments were made while the participant was standing on a single leg and on both legs, on a firm and a foam surface, with eyes open and eyes closed and while standing and squatting. These tests were Time to Boundary [TTB] (Sims et al. 2013), the SEBT (Baltaci et al. 2013; Sims et al. 2013) and the functional squat system (Baltaci et al. 2013). The functional squat system is a computer-generated system that includes tests of coordination, proprioception and response time that focus on lower limbs squatting. This was specifically used in the Baltaci et al. (2013) study because it focuses on rehabilitation after hamstring anterior cruciate ligament reconstruction. However, the game Ski Jump, which involves balance training during squatting and standing, was not part of the Wii training. Other self-rating measures, such as the ABCS and the Lower Extremity Functional Scale [LEFS], were used. However, none of the studies included specific functional balance measures.

All studies focused mainly on regaining function after knee surgery, and balance was an essential element of the rehabilitation. All studies demonstrated positive significant balance improvements after Wii Fit training. The main balance improvements were observed for 1) single-leg standing and reaching in anterior, postero-lateral and postero-medial directions during the SEBT (Baltaci et al. 2013; Sims et al. 2013), 2) coordination and proprioception tests of the functional squat system (Baltaci et al. 2013), 3) single-leg standing AP with eyes open and ML with eyes closed of the TTB (Sims et al. 2013), 4) close to symmetrical body weight distribution during double-leg standing and 5) decreased COP sway during single-leg standing on a foam surface with eyes open and closed (Puh et al. 2014). The improvements seen in standing with eyes closed and on a foam surface points to the effect of Wii Fit training on standing balance by increasing the joint proprioception sensation. This is due to the standing and body weight shifting requirements of Wii Fit games, which increase the sense of load on joints based on the visual feedback of the game avatar. This highlighted the mechanical and sensory integration effects of Wii Fit training. However, the results of the three RCT studies showed no significant differences between groups. This means that the Wii Fit training has an equal effect to conventional rehabilitation, lower limb exercises and balance exercises, even when it was conducted alone or as an add-on therapy to traditional therapy.

Table 3.6: Studies that tested the effect of Wii Fit balance games on adults with Knee and lower limb surgeries

Study	Sample	Groups	Wii Fit training	Assessment	Results
Fung et al. 2012	n=50 Adults following TKR surgery	2 groups; 1- Wii Fit n=27 2- Control [lower limb exercise] n=23	15 min, 2/week until discharge [about 6 weeks], 6 balance games & 3 yoga games + 60 min regular PT	On 1st day and every 2 weeks by blinded assessor with; ROM, 2MWT, NPRS, LEFS, ABCS, LOR	No significant difference was found between groups in any of the measures
Baltaci et al. 2013	n= 30 Adults following ACL reconstruction	2 groups {n=15 each}; 1- Wii Fit 2- Rehab	1 h, 3/week for 12 weeks, 3 balance games & 2 Wii Sports games	On 1st week, 8th week & 12th week with; SEBT, functional squat system {coordination, proprioception & response time}, knee muscle strength	No significant differences between groups, but Significant improvements in both groups in anterior & PM SEBT, coordination and proprioception tests
Sims et al. 2013	n= 28 Adults with history of LLI	3 groups; 1- Wii Fit, n=9 2- Balance exercise n=10 3- Control n=9	15 min, 3/week for 4 weeks, 5 balance games, 4 strength games, 3 aerobics games, 3 yoga games	Baseline, 2 weeks & 4 weeks by blinded assessor with; TTB, SEBT, LEFS	Both intervention groups improved in TTB [EOAP & ECML directions] and SEBT [PM & PL] after 4 weeks, But No significant differences between them
Puh et al. 2014	n=1 Adult following PCL reconstruction	-	30-45 min, 6/week for 4 weeks, 5 balance games, 3 yoga games	Before and after training with; joint ROM, limb circumferences, COP length, sway area, & velocity during single or double leg standing	Symmetrical weight bearing, decrease COP sway during one leg standing on complaint surface, increase ROM and decrease circumferences

2MWT= two minute walk test, ABCS= Activity-specific balance confidence scale, ACL= anterior cruciate ligament, COP= centre of pressure, EOAP= eyes open anterior to posterior direction, ECML= eyes closed medial to lateral direction, LEFS= Lower extremity functional scale, LLI= lower limb injury, LOR= length of outpatient rehabilitation, NPRS= numeric pain rating scale, PCL= posterior cruciate ligament, PL= posterolateral, PM= posteromedial, ROM= range of motion, SEBT= star excursion balance test, TKR= total knee replacement, TTB= time to boundary

3.4.1.3 Stroke

The literature related to including Wii games in stroke rehabilitation started by studying the efficacy of using Wii Sports in upper limb rehabilitation(Saposnik et al. 2010; Yong-Joo et al. 2010; Mouawad et al. 2011). Although Wii Sports games are not directly related to balance training because they do not include balance games, they have been shown to be effective in stroke rehabilitation. Existing studies have investigated the use of Wii Fit games for balance training with chronic stroke patients (Deutsch et al. 2009; Cho et al. 2012; Barcala et al. 2013; Ding et al. 2013; Hung et al. 2014; Omiyale et al. 2015; Yatar & Yildirim 2015) and subacute stroke patients (Sugarman et al. 2009; Morone et al. 2014). Table 3.7 shows details of the nine studies that have tested the effect of Wii Fit balance training on adults who experienced stroke.

3.4.1.3.1 Study design

The level of research about the use of Wii Fit games for the stroke population is considerably high. Four studies were designed as randomised controlled trials (Barcala et al. 2013; Hung et al. 2014; Morone et al. 2014; Yatar & Yildirim 2015). The other five studies varied between a randomised controlled pre- and post- test design (Cho et al. 2012), a group pre- and post- test design without controls (Omiyale et al. 2015), a preliminary case study (Ding et al. 2013) and case studies (Deutsch et al. 2009; Sugarman et al. 2009). Except for the three case studies, the sample size ranged between 10 and 50 participants. However, only Yatar & Yildirim (2015) demonstrated a power calculation for the sample size. In addition, about three randomised controlled trials had a sample size of 30 participants or more (Hung et al. 2014; Morone et al. 2014; Yatar & Yildirim 2015), which was the required sample based on the power calculation of Yatar and Yildirim (2015). Five studies randomly allocated participants into two groups, a Wii Fit group and a control group. The control group was either a conventional physiotherapy group with no add-on training (Cho et al. 2012; Barcala et al. 2013) or a conventional physiotherapy group with extra balance training (Hung et al. 2014; Morone et al. 2014; Yatar & Yildirim 2015), All employed a rigours method of randomisation, and no significant differences were found between groups at baseline.

3.4.1.3.2 Wii Fit training

The Wii Fit balance training used in eight out of nine studies were based on a selection of balance games only (Sugarman et al. 2009; Cho et al. 2012; Barcala et al. 2013; Ding et al. 2013; Hung et al. 2014; Morone et al. 2014; Omiyale et al. 2015; Yatar & Yildirim 2015). Only one study used a mix of Wii Fit games and Wii Sports games in training (Deutsch et al. 2009). This means that the results of almost all studies presented reflect the effect of specific Wii Fit balance games. In addition, most of the studies agreed on a Wii fit training duration of four to six weeks (Deutsch et al. 2009; Cho et al. 2012; Barcala et al. 2013; Morone et al. 2014; Omiyale et al. 2015; Yatar & Yildirim 2015). Only Hung et al. (2014) had a long training duration of 12 weeks, and on the extreme other end, Ding et al. (2013) studied the effect of one week of Wii Fit training. The timing of training sessions and the number of sessions per week varied across studies, ranging from 20 min to one-hour sessions and from two to three sessions a week. Although a one-hour session is considered long and may not be practical for a rehabilitation clinic, Ding et al. (2013) asked two participants to play one Wii Fit game for three hours. However, Ding et al. (2013) conducted an experiment that included adjusting the level of pressure on the WBB while playing Wii Fit games for stroke patients to test the efficiency of the WBB sensors' modifications and not the effect of the games on balance over time. Therefore, the intensity and duration of Wii Fit training was three hours daily for one week. Although this intensive duration has shown favourable outcomes, it is not convenient in rehabilitation settings.

3.4.1.3.3 Outcome measures

Assessment took place before and after training; however, four studies continued with follow-up assessments after one month (Morone et al. 2014; Yatar & Yildirim 2015) or after three months (Deutsch et al. 2009; Hung et al. 2014). This showed the long-term effects of Wii Fit and whether the effect was maintained. All studies included a blinded assessor, except those of Cho et al. (2012) and Yatar and Yildirim (2015). This excludes any assessment bias and confirms the consistency of the results.

The outcome measures used were clinical functional measures of balance or balance mobility, such as BBS, TUG and FRT. In addition, standing posturography outcomes, such as body weight-bearing symmetry, COP sway area, COP length and COP velocity, were also used as outcome measures. These laboratory outcomes were calculated while participant were standing on an force plate (Cho et al. 2012; Barcala et al. 2013), an interactive balance system (Hung et al. 2014) and a WBB (Ding et al. 2013; Omiyale et al. 2015; Yatar & Yildirim 2015). Three studies used the WBB in balance assessments. The WBB is a reliable and valid tool when it connects to calculating software to produce accurate outcomes. However, only Yatar and Yildirim (2015) used the WBB to assess the percentage of weigh distribution using a balance test within the Wii Fit game, which is neither reliable nor valid (Gras et al. 2009). In addition, Omiyale et al. (2015) used the score of one of the Wii Fit games 'Soccer Heading' as an outcome measure. However, the Wii Fit game scores have been shown to be unreliable assessments of balance (Wikstrom 2012).

Including both static and dynamic measures of balance is a strength in most studies that shows the separate effects of each type of training. Other than balance outcomes, different measures were used that assess other outcomes related to balance, such as walking ability and speed {gait speed, gait dynamic index, 6MWT, 10MWT, functional ambulatory category}, activities of daily living [ADL] measures {the Frenchay Activity Index, the Barthel Index and the functional independence Measure [FIM]} and balance confidence scales {the ABCS and Falls Efficacy Scale International [FESI]}. However, only Omiyale et al. (2015) assessed corticomotor excitability with transcranial magnetic stimulation [TMS]. Such different outcome measures give a broader idea of what aspects the Wii Fit training can possibly benefit. In addition, they draw attention to the importance of the effect of Wii Fit training not only on balance activities but on functional daily activities.

3.4.1.3.4 Results

Three case studies were found that gave an idea about the potential effect of Wii Fit training on dynamic balance. Sugarman et al. (2009) showed a significant decrease in TUG of 10 s after training with Wii Fit for an adult with subacute stroke. This significant improvement could be due to intensive rehabilitation. Deutsch et al. (2009) trained two adults with chronic stroke with either Wii Fit or conventional rehabilitation. The subject trained with Wii Fit demonstrated greater improvement; however, it was not maintained after three months. Ding et al. (2013) had a sample of three adults with chronic stroke, two of which trained using Wii Fit games and one of which served as the control. The results showed that using the Wii fit games increased weight bearing on the paretic limb. However, this study was not designed to test the effect of training but to introduce a new method of constraint-induced movement therapy to encourage weight shifting on the paretic limb. This was done by adjusting the weight on the sensors of two WBBs while playing the Wii Fit games. This will encourage the patient to weight shift more onto the paretic limb to win the game. Although this method has shown significant benefit by increasing symmetrical weight bearing, it needs to be investigated further with a larger sample.

Conventional rehabilitation is essential for stroke patients; thus, all studies include physiotherapy as regular training for all participants. However, two studies added the Wii Fit balance training to conventional physiotherapy for the intervention group only (Cho et al. 2012; Barcala et al. 2013). The other three studies included add-on training, either Wii Fit or balance training, for both groups (Hung et al. 2014; Morone et al. 2014; Yatar & Yildirim 2015). However, they all agreed that there were no differences between balance training with Wii Fit or conventional balance training, as both provide positive significant improvements after dynamic balance training in terms of BBS, TUG and FRT, and in static balance in terms of COP sway and the stability index. This supports the findings of previous studies conducted with older adults, where Wii Fit was not found to be superior to any other form of training. In contrast, Cho et al. (2012) and Morone et al. (2014) both claim that significant changes were seen in the disability level assessed using the Barthel index and in dynamic balance in terms of BBS and TUG in the Wii Fit group. However, Cho et al. (2012) had the limitation of an assessor who was not blinded, and Morone et al. (2014) had a smaller sample at the time of analysis due to a high dropout rate.

Omiyale et al. (2015) showed that Wii Fit training is effective in increasing inter-hemispheric symmetry, which in turn increases corticomotor excitability in the paretic limb and decreases it in the non-paretic limb. This was assessed by motor-evoked potentials of the tibialis anterior muscle with TMS. This indicates the effect of training with Wii Fit games on increasing symmetrical weight bearing for chronic stroke patients. In addition, when patients were asked to perform dynamic weight shifting tasks on the WBB, they showed a significant decrease in reaction time after training. However, other measures of the percentage of weight bearing distribution were not significantly improved. This may be due to the short training duration of three weeks.

Most studies agreed that the effect of Wii Fit training was significant in dynamic balance tasks such as BBS, TUG and FRT. The most significant results were for the TUG test, showing that the effect of Wii Fit may be related to walking measures due to the nature of the games' training by weight shifting. Additionally, significant improvements were seen in the performance of the TUG dual task, which shows the effect of training on improving cognitive ability. In contrast, there were no significant changes in terms of static standing balance measures, such as COP sway area or velocity. However, body weight bearing during standing became more symmetrical, and more weight was applied on the paretic limb after training with Wii Fit. Hung et al. (2014) showed significant changes in stability index scores during standing in different sensory conditions, such as standing on a foam surface, with eyes closed or with the head turned to left. This confirms the effect of Wii Fit training on vestibular and somatosensory systems.

Although significant changes in dynamic balance after Wii Fit training were seen, the maintenance of such improvements over time was not consistent after one month (Yatar & Yildirim 2015) or three months (Deutsch et al. 2009; Hung et al. 2014). In fact, control groups showed maintenance of improvement at follow-up assessments more than participants trained with Wii Fit (Deutsch et al. 2009; Yatar & Yildirim 2015). This may be because conventional rehabilitation is more adaptable to suite patients' needs or because the effect of Wii Fit is only for short period. On the contrary, Morone et al. (2014) showed that participants in the Wii Fit group maintained a significant difference in BBS and BI after training and at the one-month follow-up. However, this may not be considered because of the high dropout rate by the one-month follow-up assessment. In addition, the sample was composed of subacute stoke patients who may give different results than chronic stroke patients. The level of enjoyment was high among most study participants and safety was ensured as there was no adverse event. However, most studies agreed that Wii Fit training is better conducted with supervision as patients may easily perform unwanted compensation movements that do not address the training required.

Table 3.7: Studies that tested the effect of Wii Fit balance games on adults with Stroke

Study	Sample	Groups	Wii Fit	Assessment	Results
Deutsch et al 2009	n=2 chronic stroke [aged 48 & 34 y/o]	1 Wii Fit & Sport 1 Standard care	1 h, 3/week for 4 weeks 3 Wii Sport games, Wii Fit; 3 balance games, 1 strength game & 1 aerobic game	Before, after training and 3 months follow up with; 6MWT,DGI, ABC, TUG & Dual TUG	Improvements were seen in both, greater improvement was for the Wii training but retention of improvement was greater for the stranded care
Sugarman et al 2009	n=1 subacute Stroke aged 86 y/o	-	45 min, 4 days 4 balance games	Before & after training with; BBS, FRT, TUG, stability index	Significant decrease in TUG [10 sec]. Modest improvements in other measures
Cho et al 2012	n=22 chronic stroke [mean age 65 y/o]	2 groups {n=11 each}; 1- Rehab+ Wii Fit 2- Rehab [control]	30 min, 3/week for 6 weeks[Rehab; 60 min, 5/week] 6 balance games	Before and after training with; COP length & velocity [static] and BBS, TUG [dynamic]	Significant improvement in BBS & TUG after training in the Wii Fit group. No significant changes of COP measures after training
Ding et al 2013	n=3 chronic stroke [55, 71, 78 y/o]	2; adjusted Wii fit games with 2 WBBs 1; control [rehab only]	3 h, daily for 1 week 1 balance game {Ski Slalom}	Daily for 3 weeks[1 week before & 1 week after] with; COP tracking test & weight distribution [standing on 2 WBBs]	Increased weight bearing on the paretic limb during Wii Fit compared to conventional rehabilitation
Barcala et al 2013	n=20 chronic stroke [mean age 65 y/o]	2 groups {n=10 each}; 1- Wii Fit + PT 2- PT [control]	30 min, 2/week for 5 weeks 3 balance games	Before & after training with; BBS, TUG, FIM, COP sway & body symmetry	Significant improvements in all outcomes in both groups, no difference between them

Morone et al 2014	n=50 Subacute stroke [mean age 60 y/o]	2 groups; 1- Wii Fit {n=25} 2- Balance therapy {n=22}	20 min, 3/week for 4 weeks 3 balance games	Before, after training & 1 month follow up with; BBS, 10MWT, FAC & BI	The Wii Fit group showed significant improvements in BBS & BI more than controls, and maintained after 1 month
Hung et al 2014	n=30 chronic stroke [mean age 55 y/o]	2 groups {n=15 each}; 1- Wii Fit 2- Weight shifting	30 min, 2/week for 12 weeks 7 balance games	Before, after training and 3 months follow up with; [static] stability index & body weight bearing. [dynamic] FRT, TUG, FESI, PACES	Significant time x group interaction in stability index in HSEOF, H30LECS, HUECSS positions after training. Significant improvements in TUG & FRT in both groups after training & after 3 months
Omiyale et al 2015	n=10 chronic ischemic stroke	One group	60 min, 3/week for 3 weeks 5 balance games	Before & after training with; 1- MEP recruitment curves {for TA with TMS} 2- Static & dynamic body weight distribution {by COP with WBB} 3- The Soccer Heading game score, Clinical; TUG, Dual TUG, BBS, gait speed, & ABC	Significant findings after training in; 1- Increase in inter-hemispheric symmetry & decrease in non-paretic limb recruitment curves 2- Decrease in reaction time during dynamic weight shifting 3- Increase in Soccer Heading game score, Improvements in only Dual TUG & ABC
Yatar & Yildirim 2015	n=30 chronic stroke	2 groups {n=15 each}; 1- Wii Fit balance 2- balance training	30 min, 3/week for 4 weeks 3 balance games	Before, after training & 1 month follow up with; % of weight distribution on WBB, BBS, TUG, DGI, FRT, ABC, FAI	Significant improvements in both groups after training & no significant difference between groups

6MWT= six minute walk test, 10 MWT= Ten Meter Walk Test, ABC= Activity specific balance confidence, BBS= Berg Balance Scale, BI= Barthel Index, COP= Centre of Pressure, DGI= Dynamic Gait Index, FAC= Functional Ambulatory Category, FAI= Frenchay Activity Index, FES-I= Falls Efficacy Scale International, FIM= Functional Independence measure, FRT= Functional Reach test, HSEOF= Head Straight with Eyes Open on Foam Surface, HUECS= Head Up with Eyes Closed on solid Surface, H30LECS= Head at 30 Left with Eyes closed on solid surface, MEP= Motor Evoked Potentials, PACES= Physical Activity Enjoyment Scale, TA= Tibialis Anterior, TMS= transcranial magnetic stimulation, TUG= Timed Up and Go, WBB= Wii Balance Board

3.4.1.4 Parkinson's disease

Adults with PD experience loss of postural stability that can be improved through physical therapy and balance exercises. There is growing interest in physical exercise through games as a promising rehabilitation tool; however; the evidence is still limited. Seven studies were found that investigated the effect of Wii Fit games on balance for adults with PD (Zettergren et al. 2011; Esculier et al. 2012; Loureiro et al. 2012; Mendes et al. 2012; Pompeu et al. 2012; Mhatre et al. 2013; Holmes et al. 2013a). A summary of the study methods and results is presented in Table 3.8.

3.4.1.4.1 Study design

Of the seven studies, only one study was designed as an RCT (Pompeu et al. 2012) and only one as a case study (Zettergren et al. 2011). The other five studies were designed as clinical controlled trials (Esculier et al. 2012; Loureiro et al. 2012; Mendes et al. 2012; Mhatre et al. 2013; Holmes et al. 2013a). The sample size in all studies was relatively small at 6–16 adults with PD (Esculier et al. 2012; Loureiro et al. 2012; Mendes et al. 2012; Mhatre et al. 2013; Holmes et al. 2013a), except for Pompeu et al. (2012), where the sample size was 32 adults with PD. However, a power calculation of the sample was demonstrated in four studies (Esculier et al. 2012; Mendes et al. 2012; Pompeu et al. 2012; Mhatre et al. 2013).

Three studies included one group of adults with PD (Loureiro et al. 2012; Mhatre et al. 2013; Holmes et al. 2013a). The other three studies included two groups; two studies compared adults with PD to healthy controls (Esculier et al. 2012; Mendes et al. 2012) and one compared two groups of adults with PD (Pompeu et al. 2012). Comparing the results of a randomised sample to two groups with two different training methods is a strength in the study by Pompeu et al. (2012). However, comparing between healthy adults and adults with PD, as in Esculier et al. (2012) and Mendes et al. (2012), may not represent the true effect of Wii Fit training but instead shows the effect of Wii Fit training in each group as a separate sample. However, Mendes and colleagues (2012) evaluated the learning process of adults with and without PD when using the Wii Fit games to compare the learning curve and identify learning deficits. This study mainly looked at the Wii Fit games and their suitability for adults with PD. However, an effect of Wii Fit learning on FRT was demonstrated in this study to show the transfer of learning from the games to motor task that was not trained like the functional reach.

3.4.1.4.2 Wii Fit training

The Wii Fit balance training used in these studies consisted of balance games only (Loureiro et al. 2012; Mhatre et al. 2013; Holmes et al. 2013a), balance games with aerobics games (Mendes et al. 2012; Pompeu et al. 2012) or balance games with Wii Sports games (Esculier et al. 2012). The training duration was between five and eight weeks in all studies except that by Holmes et al. (2013a), which was 12 weeks. Although Holmes et al. (2013a) had the longest duration of training, it was the only study that did not show any significant changes. This may indicate that longer training duration may not be more effective than shorter duration.

Adults with PD undergo physiotherapy or occupational therapy sessions, but in most of the studies, the sample was selected to avoid any participant who undertook such sessions. This means that the effect of Wii Fit training in these studies was without the influence of extra therapy sessions.

Two studies conducted Wii Fit training at in a home setting to explore the flexibility of Wii Fit as a home exercise and its effects (Esculier et al. 2012; Holmes et al. 2013a). The results were controversial; Esculier et al. (2012) reported significant improvements in dynamic functional measures and static force plate measures for both healthy adults and adults with PD. Holmes et al. (2013a) reported that Wii Fit training at home did not result in any significant differences in COP length during static standing for adults with PD. Surprisingly, the Wii Fit training duration in the study by Holmes et al. (2013a) was 12 weeks, which was doubled the training duration in the study by Esculier et al. (2012). However, the participants in the study by Esculier et al. (2012) were composed of adults with PD and their healthy partners; this may have motivated adults with PD to train more. In addition, Holmes et al. (2013a) only looked at static measures of balance and did not include other functional assessments of dynamic balance. Although both studies demonstrated the convenience of Wii Fit training at home for adults with PD, neither considered the safety of training at home. Additionally, calculating the time spent playing the games, which was recorded in the game console, is not a rigorous method to show adherence to training, especially when the games were played at home where it could be anyone playing the games and not necessarily the study participants.

3.4.1.4.3 Outcome measures

The outcome measures used in these studies were either functional measures of dynamic balance alone (Zettergren et al. 2011; Loureiro et al. 2012; Mendes et al. 2012; Pompeu et al. 2012), laboratory measures of static balance alone (Holmes et al. 2013a) or both measures (Esculier et al. 2012; Mhatre et al. 2013). The main functional balance assessments used were the BBS, the TUG and the FRT. Other functional assessments related to balance were also used, such as the sit-to-stand test, the 10 meter walk test and CBM (Esculier et al. 2012), the dynamic gait index (Mhatre et al. 2013), the unipedal stance test (Pompeu et al. 2012) and the Borg scale (Loureiro et al. 2012). In addition, Pompeu et al. (2012) used Section II of the Unified Parkinson's Disease Rating Scale [UPDRS-II], which is an activity of daily living functional performance assessment for adults with PD. All functional measures listed showed significant improvements after Wii Fit training. However, in the majority of the studies, the assessor was not blinded; the exception was the study by Pompeu et al. (2012).

Standing COP parameters were also used as an outcome measured via force plate. These parameters were the resultant RMS of COP velocity during single-leg standing (Esculier et al. 2012) and the COP total length (Holmes et al. 2013a). The results were not promising, as Esculier et al. (2012) claim that a significant change in the RMS of COP velocity during single-leg standing with eyes open has occurred after training. This may not indicate improvement in static balance. Holmes et al. (2013a) did not find any significant differences in COP length during double standing. The static balance assessed by quantitative COP parameters either via force plate or a WBB showed a real measure of change; however, using the WBB with Wii Fit balance tests may not allow quantifying movement but will just result in a test score. Therefore, using the Wii Fit tests as a balance assessment is not recommended because the scores are not reliable (Wikstrom 2012). Thus, the significant changes found in standing balance with eyes open seen in the results of Mhatre et al. (2013) is not an indication of improvement.

3.4.1.4.4 Results

Assessments were conducted before and after training in all studies; however, some included a mid-point assessment (Esculier et al. 2012; Holmes et al. 2013a) and some included a two-month follow-up assessment (Mendes et al. 2012; Pompeu et al. 2012). The results at the mid-point assessments and follow-up assessment were consistent with the results after training. The results from almost all studies showed significant improvements in balance outcome measures, except for that by Holmes et al. (2013a). A significant increase in the BBS after Wii Fit training was seen in four studies (Zettergren et al. 2011; Loureiro et al. 2012; Pompeu et al. 2012; Mhatre et al. 2013). There was a significant decrease in the TUG in two studies (Zettergren et al. 2011; Esculier et al. 2012). There was a significant increase in time spent in single-leg standing (Esculier et al. 2012; Pompeu et al. 2012), which is an indication of better postural control. In addition, significant improvements were seen in gait measures (Zettergren et al. 2011; Esculier et al. 2012; Mhatre et al. 2013), which shows the effect of Wii Fit training on gait performance. However, as discussed earlier, there is a lack of significant results in terms of laboratory measures of static balance.

Other effects of Wii Fit training were tested in some studies, such as the cognitive effect (Pompeu et al. 2012) and the learning effect (Mendes et al. 2012). The effect on cognitive level as assessed by the Montreal Cognitive Assessment significantly improved immediately after Wii Fit training and was maintained for two months. In addition, Mendes et al. (2012) selected Wii Fit games that include motor demands like weight shifting or alternating steps and cognitive demands like focusing, planning and decision making. Adults with PD demonstrated improvements in the games scores after training, and the learning curve was similar to healthy controls in seven of the 10 games selected. This shows the cognitive and motor effects of the Wii Fit games. However, Mendes et al. (2012) showed that adults with PD had learning deficits and poorer performances than healthy controls in three games that required fast decision making and movements to avoid virtual obstacles. This shows the importance of selecting the proper games for each population.

The positive effect of Wii Fit training on balance for adults with PD, which was demonstrated in the studies found, was mainly in terms of dynamic balance {not static}, gait, cognitive and functional ADL improvements. Although most results showed a positive effect of Wii Fit training, there is still limited evidence to support this, as there was only one RCT out of the seven studies found. In addition, adults with PD who were included in these studies were carefully selected and had relatively mild symptoms {Hoehn & Yahr stage I & II}. Therefore, the results must be interpreted with caution. A home setting was suggested as an option for Wii Fit training, but there was no subjective or objective measures of safety reported in any of the studies.

Table 3.8: Studies that tested the effect of Wii Fit balance games on adults with PD

Study	Sample	Groups	Wii Fit training	Assessment	Results
Zettergren et al 2011	n=1 male with PD aged 69 y/o	-	40-60 min, 2/week for 8 weeks, 3 balance games, 1 gait game, 5 stretching games	Before & after training with; TUG, BBS, gait speed [self-selected], fall history, GDS	Significant decrease of TUG [by 12 sec], significant increase in BBS [by 11 points], & gait speed increased [by 0.11 m/sec] after training
Mendes et al 2012	n=27 PD & healthy elderly	2 groups; 1- PD {n=16} 2- Healthy controls {n=11}	60 min, 2/week for 7 weeks, 5 balance games, 5 aerobic games	During 7 training sessions & 1 session at 60 days follow up with the learning curve of scores of 10 games. Before training & at 60 days follow up with FRT	Significant improvement in FRT after training and at 60 days follow up. Only 3 games showed significant learning deficit for PD when compared to controls
Esculier et al 2012	n= 20 PD & healthy elderly [mean age 63.5 ± 12.0]	2 groups; 1- PD {n=10} 2- Healthy controls {n=8}	Home training 40 min, 3/week for 6 weeks, 30 min; 5 balance games, 10 min; 2 Wii Sports games	Before, mid [week 3], & after training with; STST, TUG, 10MWT, CBM, ABCS, POMA and Single leg stance on force plate {duration & RMS COP velocity}	Significant improvements in the CBM, STST, TUG & duration of single-leg stance at 3 & 6 weeks for both groups Significant improvements in the 10MWT, POMA & COP RMS velocity at 3 & 6 weeks for the PD only
Pompeu et al 2012	n= 32 PD aged 60-85 y/o	2 groups {n=16 each}; 1- Wii fit games 2- balance exercises	30 min, 2/week for 7 weeks, 6 balance games, 4 gait games	Before, after training & at 60 days follow up by blinded assessor with; UPDRS-II, BBS, Uni-pedal Stance Test, MCA	Both groups showed a significant improvement on the UPDRS-II, BBS, Uni-pedal Stance Test & MCA after training & at follow-up. No difference between groups

Loureiro et al 2012	n=6 PD with mean age 65 ± 13 y/o	One group	20 min, 2/week for 5 weeks, 5 balance games	Before and after training with; Borg's Scale, BBS, TUG, FRT and Nottingham's Scale	Significant improvements were found in the Borg's Scale, BBS, FRT [lateral right & left] after training
Holmes et al 2013a	n=11 PD aged 58-75 y/o	One group	Home training 30 min, 3/week for 12 weeks, 7 balance games	Before, mid [week 6] & after training with; COP length & ABCS	No significant improvements were found
Mhatre et al 2013	n=10 PD aged 44-91 y/o	One group	30 min, 3/week for 8 weeks, 3 balance games	Before & after training with; BBS, DGI, SRT, COP [standing with eyes open & closed] and tracking tasks using WBB, ABCS & GDS	Significant improvements in BBS, DGI, COP standing with eyes open & COP tracking after training

10MWT= ten minute walk test, ABCS= Activities-specific Balance and Confidence scale, BBS= Berg Balance Scale, CBM= Community Balance and Mobility assessment, COP= Centre of pressure, DGI= Dynamic Gait Index, FRT= functional reach test, GDS= Geriatric Depression Scale, MCA= Montreal Cognitive Assessment, POMA= Tinetti Performance Oriented Mobility Assessment, SRT= Sharpened Romberg test, STST= Sit-to-Stand test, TUG=Timed Up & Go, UPDRS-II= Section II of the Unified Parkinson Disease Rating Scale, WBB= Wii Balance Board

3.4.1.5 Brain injury

Adults who experience brain injury are entitled to intensive inpatient rehabilitation. Balance training is part of the rehabilitation programme as it is essential for functional ADL. Including virtual reality or gaming as a form of balance training is newly proposed to this population. Therefore, the literature related to using the Wii Fit games for balance training for TBI survivors is still limited. The studies found were conducted with adults and children with brain injuries. However, the studies of children with brain injuries will be discussed in a different section. This section will only focus on the studies of adults with brain injuries (Table 3.9), which consisted of two feasibility studies (McClanachan et al. 2013; Cuthbert et al. 2014).

The studies have some similarities in terms of the sample, the settings and the training duration. Both studies recruited 20 participants with TBI who are undertaking intensive rehabilitation in inpatient settings. In addition, both studies used Wii Fit training for the same duration of four weeks. The differences lie in the study design, type of games, outcome measures and findings. The study by Cuthbert et al. (2014) is a feasibility single blind RCT, whereas that by McClanachan et al. (2013) is a randomised cross-over trial. Although both had same sample size, it was not powered and was relatively small. In addition, there was a dropout rate due to early discharge. This means that the results were based on a smaller sample; however, both studies used the intention to treat analysis to overcome this issue. In each study, there were two groups to compare the effect of Wii Fit training as an add-on intervention (McClanachan et al. 2013) or to compare it with another form of balance training (Cuthbert et al. 2014). While both claimed that group allocation was randomised, the randomisation method was not mentioned.

The Wii Fit training duration was four weeks, but the intensity of training was different. It was three 30 min sessions per week in the study by McClanachan et al. (2013) and four 15-min sessions per week in that by Cuthbert et al. (2014). In addition, neither of the studies included only Wii Fit balance games but mixed it with other Wii Fit aerobics games (McClanachan et al. 2013) or with Wii Sports games (Cuthbert et al. 2014). Both studies showed a good level of enjoyment expressed by the participants; however, the Cuthbert et al. (2014) study showed no difference between the enjoyment level when trained with Wii Fit or the usual care. This may be due to the limited games selected, which was only two in each session and which may have resulted in boredom.

The outcome measures used in both studies were mainly looking at feasibility aspects, such as acceptability, adherence, safety and enjoyment. In addition, outcome measures related to balance, gait and endurance were used. These outcome measures were mainly functional clinical assessments of balance, while only one laboratory measure of gait was used (McClanachan et al. 2013). Neither of the studies included the use of force plates to measure COP movement during static standing balance. This is because the studies' aims were mainly to test feasibility and overall functional improvement and not balance specifically. Despite this, functional dynamic balance assessments like the BBS (Cuthbert et al. 2014) and the Balance Outcome Measure for Elder rehabilitation (McClanachan et al. 2013), which is an assessment tool that includes items similar to the TUG and the FRT tests, were used. In addition, other outcome measures that assess gait, such as functional gait assessment (Cuthbert et al. 2014) and gait speed (McClanachan et al. 2013), can show improvement in terms of balance during gait. Assessments were conducted by a blinded assessor in both studies at mid training and after training (Cuthbert et al. 2014) or after training and after four weeks without training (McClanachan et al. 2013). However, the results were only significant after four weeks of training.

Cuthbert et al. (2014) found a significant positive correlation between the BBS score and the scores of two Wii Fit games, the Table Tilt and the Penguin Slid. They also suggest using the game scores as an indication of balance improvements, which is not acceptable for different reasons. The rho correlations were 0.68 and 0.69, and the 95% CIs were 0.09-0.92 and 0.12-0.92 between the BBS and Table Tilt and Penguin Slide games scores respectively. These results showed a high range of CI indicating a high variability and unreliability of the scores. In addition, the significant correlations presented were only found at mid assessment {two weeks} for the Table Tilt and at final assessment {four weeks} for the Penguin Slide. This means that this correlation was not consistent. Furthermore, these games were the only two Wii Fit games used for training, and their results cannot be generalised to all Wii Fit games as each game has a different scoring system.

The results of both studies showed a positive significant effect of Wii Fit training on dynamic balance, gait and endurance. Significant changes were seen after the Wii Fit training block in the 6MWT and in gait speed (McClanachan et al. 2013). These changes exceeded the minimum clinical importance difference threshold for each measure. There were significant improvements in the BBS after training in the Wii Fit group only and significant changes in the functional gait assessment after training in both groups (Cuthbert et al. 2014). Neither study found any significant differences between groups. The effect of Wii Fit training on balance was not clearly tested for adults with brain injury, as both studies were designed as feasibility studies with small sample sizes, which may not show significance. Furthermore, the improvements observed could be because participants were in inpatient settings and had undergone intensive rehabilitation. Therefore, the results may not reflect the true effect of Wii Fit training.

Table 3.9: Studies that tested the effect of Wii Fit balance games on adults with brain injury

Study	Sample	Groups	Wii Fit	Assessment	Results
McClanachan et al 2013	n= 21 adults with ABI [inpatient]	2 groups [cross-over]; 1- Wii Fit + usual care {n=11} 2- Usual care alone {n=10}	30 min, 3/week for 4 weeks 4 balance games & 3 aerobic games cross-intervention between groups every 4 weeks	Before & after each block of 4 weeks by blinded assessor with; 6MWT, BOOMER, gait lab parameters, HiMat	Clinically significant Improvements in 6MWT & gait speed following training but no significant differences between interventions
Cuthbert et al 2014	n= 20 adults with TBI [inpatient]	2 groups {n=10 each}; 1- Wii Fit & Wii Sport 2- Balance rehab	15 min, 4/week for 4 weeks 2 Wii fit balance games & 2 Wii Sports games	Before, after 2 weeks & 4 weeks training by blinded assessor with; PACES, BBS, FGA	Significant improvements in BBS for Wii group only, and in FGA for both groups with no significant difference between them

6MWT= six minutes walk test, ABI= Acquired Brain Injury, BBS= Berg Balance Scale, BOOMER= Balance Outcome Measure for Elder Rehabilitation, FGA= Functional Gait Assessment, HiMat= High level mobility assessment tool, PACES= Physical Activity Enjoyment Scale, TBI= Traumatic Brain Injury

3.4.1.6 Vestibular disorder

Vestibular rehabilitation is an effective intervention for vestibular conditions, such as unilateral peripheral vestibular loss [UVL] that causes vertigo, dizziness, and impaired balance and gait. The Wii Fit games were suggested to be part of the vestibular rehabilitation as it includes motor learning and provides visual and auditory feedback. However, only two studies were found that investigated the feasibility and effectiveness of including Wii Fit games as part of vestibular rehabilitation (Sparrer et al. 2013; Meldrum et al. 2015). Details about each study are presented in Table 3.10.

The study design was different in each study; one is an RCT (Meldrum et al. 2015) and the other is a cohort study (Sparrer et al. 2013). The sample size was powered in both studies and was relatively similar—67 participants with acute vestibular neuritis [AVN] (Sparrer et al. 2013) and 71 participants with UVL (Meldrum et al. 2015). Six participants were missing in the study by Meldrum et al. (2015) at the six-month follow-up assessment. However, the intention to treat analysis applied has overcome these missing data. The study by Sparrer et al. (2013) had a higher dropout rate of 20 participants at the 10-week follow-up assessment, and these participants were excluded from the analysis. Both studies randomly allocated participants to two groups, but only one demonstrated a rigours randomisation method (Meldrum et al. 2015). This random allocation aimed to compare the effect of Wii Fit training to a placebo (Sparrer et al. 2013) or to vestibular rehabilitation (Meldrum et al. 2015). Sparrer et al. (2013) presented a third group of healthy controls, without any dizziness or vertigo, and compared their results to the two other groups. However, the demographic characteristics and the number of people in the group were not given.

The Wii Fit games selected for both studies were similar; 15 games were used in each study, including balance, yoga, and aerobics games. However, Sparrer et al. (2013) gave the participants the option to choose different six out of 15 games for each session, while Meldrum et al. (2015) pre-selected 10 out of 15 games for each session. Although training did not focus mainly on balance games, there was a variety of games in order to avoid boredom. The training duration in the study by Sparrer et al. (2013) was very short and intensive—45-min sessions twice a day for five days—because it took place in at inpatient setting. However, such intensive training may not be suitable for other rehabilitation populations like stroke patients. In contrast, the training duration in the study by Meldrum et al. (2015) was more reasonable and acceptable at 15-min sessions five times per week for six weeks. This training was conducted at patients' homes, except for one session per week in a clinical setting. This training duration and intensity was convenient, and there was a high adherence rate (Meldrum et al. 2015). However, Meldrum et al. (2015) reported that three adverse events occurred throughout the study, which brings into question the safety of Wii Fit home training. Participants in the Wii Fit group reported a significantly higher enjoyment level than the other group (Meldrum et al. 2015); however, this was assessed with a non-valid questionnaire.

The only balance measure used in both studies was the Sensory Organisation Test [SOT], which is a system assessing stability in different sensory conditions. However, there were neither clinical functional assessments of balance like the BBS used nor laboratory static standing COP measures. The main outcome measures used in both studies were related to nystagmus, assessed using Frenzel's goggles, and gait, assessed using gait speed and DGI. This was because these studies did not aim to improve motor impairment or increase daily functional activity like the case for adults with stroke and PD. Although most outcome measures were either objective laboratory or self-rating subjective questionnaires, Meldrum et al. (2015) ensured the assessor was blinded. Sparrer et al. (2013) used the Wii Fit age test, which is a not a balance test, and the "one leg figure" score, which is a yoga game score, as outcome measures that are not valid or reliable.

Sparrer et al. (2013) highlighted the effectiveness of Wii Fit training in terms of the absence of nystagmus 2.1 days earlier in the Wii Fit group than in the placebo group. This means that adults with UVL will require longer hospitalisation when not trained with Wii Fit. Both studies showed balance improvements in the SOT after training; however, this improvement was only significant in the Wii Fit group with other measures when compared to placebo (Sparrer et al. 2013). When the Wii Fit training is compared to vestibular rehabilitation (Meldrum et al. 2015), differences between groups were not significant across all outcome measures. This agrees with previous studies that the Wii Fit training is not superior to any other form of balance or vestibular training. The results of both studies were consistent in both assessments after training and at the 10-week follow-up (Sparrer et al. 2013) and the six-month follow-up (Meldrum et al. 2015), showing the long-term effect of Wii Fit training on the vestibular system. Both studies support the use of Wii Fit training as part of vestibular rehabilitation due to the positive results after training. However, these results were not clinically or statistically significant, as both studies used the median and interquartile range for analysis and comparison between groups. This did not test the effect of training in relation to time, where differences between pre-training and post-training were not clearly tested for significance. Although functional dynamic balance was not tested, improvements in gait speed and SOT shows positive changes in stability during walking and when experiencing different sensory conditions. Thus, these studies have shown Wii Fit to be an effective vestibular rehabilitation tool. This also agrees with previous studies that Wii Fit training has positive effects in terms of cognitive, vestibular and motor training.

Table 3.10: Studies that tested the effect of Wii Fit balance games on adults with vestibular loss

Study	Sample	Groups	Wii Fit	Assessment	Results
Sparrer et al 2013	n= 67 adults with AVN	2 groups; 1- Wii Fit {n=34} 2- Control {n=33}	45 min, 2/day for 5 days 4 balance games, 5 yoga games & 3 strengthening games	Before, after training & at 10 weeks follow up with; SOT, Frenzel's goggles, DHI, VSS, Tinneti questionnaire & Wii fit age	Absence of nystagmus 2.1 days earlier in Wii Fit group The Wii Fit group showed significantly better results in the SOT, DHI, VSS, Wii Fit age & Tinneti questionnaire
Meldrum et al 2015	n=71 adults with UVL	2 groups; 1- Wii Fit {n=35} 2- Vestibular rehab {n=36}	15 min, 5/week for 6 weeks [home training with 4-7 clinical session], 7 balance games, 6 yoga games & 3 aerobics games	Before training, after 8 weeks & at 6 months follow up by blinded assessor with; self-gait speed, DGI, SOT, DVA, VRBQ, ABCS, HADS	Improvements in both groups & no significant difference between groups in any measure.

ABCS= Activities-Specific Balance Confidence Scale, AVN= Acute Vestibular Neuritis, DGI= Dynamic Gait Index, DHI= Dizziness Handicap Inventory, DVA= Dynamic Visual Acuity, HADS= Hospital Anxiety and Depression scale, SOT= Sensory Organization Test, UVL= unilateral peripheral vestibular loss, VRBQ= Vestibular Rehabilitation Benefits Questionnaire, VSS= Vertigo Symptom scale

3.4.2 Children population

3.4.2.1 Children with poor balance

There were limited studies in the literature that investigated the effect of Wii Fit balance training on children with impaired balance. Table 3.11 provides a summary of the nine studies found regarding the effect of Wii Fit games on balance for children with poor balance due to different diagnoses. Two studies included children identified with poor balance performance at school (Mombarg et al. 2013; Jelsma et al. 2014). Other studies were performed with children with a range of diagnoses that affect their balance ability: DCD (Ferguson et al. 2013; Hammond et al. 2014); DS (Abdel-Rahman 2010); developmental delay (Salem et al. 2012); lower limb amputation (Andrysek et al. 2012); TBI (Tatla et al. 2014) and MoA (Esposito et al. 2013). These studies will be discussed based on 1) age of children, 2) sample size and study design, 3) settings and intensity of training, 4) outcome measures used and 5) the main findings.

3.4.2.1.1 Age of children

Most of the studies have investigated children population between the ages of 6 and 14, except two studies included younger or older range like; between the age of three and five years (Salem et al. 2012), or up to the age of 18 (Andrysek et al. 2012). Age is a major factor in the development of balance where all sensory systems are maturing at different rates. Therefore, it could be argued that the balance improvements seen in the studies could be due to the development of balance with age and not due to the Wii Fit training. However, the Wii Fit training was mostly for six weeks, and maturation requires a longer period of time. In addition, some studies tested balance after a control period of not playing Wii Fit and found that the balance level had declined (Andrysek et al. 2012; Hammond et al. 2014; Jelsma et al. 2014). Therefore, balance improvements are less likely to be due to the development of sensory systems.

3.4.2.1.2 Sample size and study design

Although each study investigated children with different diagnoses, all agree on the effectiveness of Wii Fit in improving balance. However, their results' dissemination to wider population is limited to the sample size. Except for Esposito et al. (2013) who recruited 71 children with MoA, the sample size ranged between 3 and 46 participants in eight studies. However, the number of children who played Wii Fit in these studies was fewer than 28. The average sample size was relatively small, which could be due to the difficulty of recruiting children with these diagnoses. In addition, these sample sizes were not powered; a power calculation of the sample size was only demonstrated in one study (Ferguson et al. 2013). Therefore, there is a need for studies with larger sample sizes that are statistically powered.

The study design used in most of the studies was a controlled pre- and post-test, which compares between outcome measures before and after intervention within one group (Andrysek et al. 2012) or between two groups, an intervention group and a group of TD children (Andrysek et al. 2012; Esposito et al. 2013; Jelsma et al. 2014) or a control group without intervention (Abdel-Rahman 2010; Salem et al. 2012; Mombarg et al. 2013). Comparing the outcomes with a control group of TD children does not show the real effect of Wii Fit training. This is because children without balance deficits will definitely have different results than children who experience difficulty in balance performance. Therefore, this comparison is only to have reference data for TD children and not to explore the effect of Wii Fit training. However, a control group from the same diagnosis sample that does not undertake Wii Fit training would allow a fairer judgment of the intervention.

Other studies compared between Wii Fit intervention and other forms of training, such as traditional balance rehabilitation (Salem et al. 2012), neuromotor task training (Ferguson et al. 2013) and a local school programme called ‘Jump Ahead’ (Hammond et al. 2014). The intent of such a comparison is to show the superiority of one intervention over another; however both interventions have to have the same duration of training. This was only seen in the study by Salem et al. (2012). The other two studies showed unequal training, where one was longer or more intensive than the other (Ferguson et al. 2013; Hammond et al. 2014). In addition, only four studies showed random allocation of groups (Salem et al. 2012; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014).

Only one study was designed to be an RCT (Salem et al. 2012). Others used different study designs, such as a multiple baseline single subject design (Tatla et al. 2014), due to a small sample size of three children, and a cross-over A-B design (Hammond et al. 2014; Jelsma et al. 2014). Although such designs do not give statistical significance, they do give an idea about potential effects. However, in order to recommend the Wii Fit as an evidence-based intervention to improve balance, more randomised control trials with larger powered sample sizes and control groups are needed.

3.4.2.1.3 Wii Fit training and settings

The intensity and duration of Wii Fit training varied somewhat across the studies, but it seems that most agreed on 30 min of training two to three times a week for a period of four to six weeks (Abdel-Rahman 2010; Andrysek et al. 2012; Ferguson et al. 2013; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014; Tatla et al. 2014). Two studies extended Wii Fit training to 10 weeks (Salem et al. 2012) and 12 weeks (Esposito et al. 2013). Even though they had different intensities of training, all showed significant improvement in balance following the Wii Fit training. Although all studies included Wii Fit games, seven involved playing balance games only (Abdel-Rahman 2010; Andrysek et al. 2012; Esposito et al. 2013; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014; Tatla et al. 2014) and the rest involved other Wii Fit games in addition to balance games (Ferguson et al. 2013) or Wii Sports games (Salem et al. 2012). Although balance games focus on shifting weight and moving the COP in different directions to improve balance, other Wii Fit games like aerobics or strengthening can improve balance too as they also require weight shifting. Different games were used across the studies; however, the positive effect of Wii Fit games on balance improvements was seen across all studies. However, the intensity of training and game selection needs to be tested with larger samples to be able to standardise the Wii Fit training programme in order to see a clinically and statistically significant effect.

The settings in which these studies were performed had an important effect on the feasibility of using Wii Fit. It can be seen from the literature that studies that recruited higher numbers of children used school settings (Ferguson et al. 2013; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014). However, these studies were performed on children with DCD, a condition that affects one in every 56 children in the UK (Lingam et al. 2009). Three studies were performed in clinical settings for children with DS (Abdel-Rahman 2010), developmental delay (Salem et al. 2012) and TBI (Tatla et al. 2014) where Wii Fit training was part of the regular therapy or as a therapy in its own. Only two studies tested the effect of Wii Fit games when used as a home therapy exercise for children with lower limb amputations and MoA (Andrysek et al. 2012; Esposito et al. 2013). Home might be the most convenient setting for children and families, where they have more freedom and flexibility in terms of the time and duration of training. However, it is easy to cheat at and manipulate Wii Fit games, making it hard to distinguish if the child has actually played the games or just run the games and make a record of it. Furthermore, a logbook may not be the most appropriate way of assessing adherence to the training or the time spent on each game. This lack of supervision is a study limitation. School and clinical settings are better supervised and convenient for children and families. The fact that Wii Fit games have been used in different settings increases the feasibility of using Wii Fit games at school, at home or at a clinic.

3.4.2.1.4 Outcome measures

Most studies assessed participants before intervention and after intervention. Only one included a follow-up assessment after about six weeks of no training (Andrysek et al. 2012). Tatla et al.

(2014) was the only study that included daily measurement assessments, which was because of the small sample size of three participants. Assessment bias is usually avoided when the investigator is blinded to group allocation or intervention. This was seen in only three studies (Salem et al. 2012; Ferguson et al. 2013; Tatla et al. 2014).

The outcome measures used in these studies were based on functional outcome measures, laboratory force plates and/or Wii Fit games and test scores. The most common functional measures were the Movement Assessment Battery for Children [MABC-2] (Esposito et al. 2013; Ferguson et al. 2013; Mombarg et al. 2013; Jelsma et al. 2014) and the Bruininks-Oseretsky test [BOT-2] (Abdel-Rahman 2010; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014). Both assess motor performance and coordination, including balance measures, which are both valid and reliable (Bruininks & Bruininks 2005; Henderson et al. 2007). Other balance functional measures like the TUG test (Salem et al. 2012; Tatla et al. 2014), the FRT (Tatla et al. 2014), the SLST (Salem et al. 2012; Tatla et al. 2014) and the CB&M (Andrysek et al. 2012) were used in a few studies. Although functional measures of balance provide valuable clinical information, other laboratory objective measures are necessary to inform about Wii Fit effectiveness. However, only one study used force platforms to measure COP sway area (Andrysek et al. 2012), and found a decrease in the COP sway area in six children with lower limb amputations after Wii Fit training, but it was not significant. Testing balance improvements with both laboratory and functional measures is needed in further studies to help determine the effectiveness of Wii Fit training in terms of static and dynamic balance.

Jelsma et al. (2014) used the scores from the Wii Fit balance game Ski Slalom as an outcome measure of balance. Game scores are based on the learning effect of playing a game many times, which does not represent balance improvement but game performance improvement. In addition, performance in this game relies on fast decision making and attention while shifting weight right and left, and the final score is calculated based on the number of gates missed as speed increase. Therefore, it is not a measure of balance. Furthermore, Wii Fit game scores are not reliable and are invalid outcome measures (Wikstrom 2012). Tatla et al. (2014) used the Wii Fit balance test as an outcome measure, which is also not valid or reliable (Gras et al. 2009). Therefore, using Wii Fit game scores or Wii Fit balance parameters is not recommended because improvements based on such measures are not clinical improvements.

3.4.2.1.5 Results

The Wii Fit training resulted in significantly greater increases in the scores of the MABC-2 and BOT-2 balance subtests when compared to no training for children with poor motor performance, DCD and DS (Abdel-Rahman 2010; Mombarg et al. 2013; Jelsma et al. 2014). A significant increase in the total MABC-2 and BOT-2 scores was shown following Wii Fit training for children with DCD (Ferguson et al. 2013; Hammond et al. 2014). However, this increase was seen in the total score and not specifically in the balance part. In addition, the study by Ferguson et al. (2013) showed greater improvements in the group that undertook neuromotor task training than in the Wii Fit group. However, this could be because the Wii Fit group was trained for six weeks, while the other group was trained for nine weeks. The study by Esposito et al. (2013) showed greater significant improvements in both the total score of the MABC and the scores for the balance part in children with MoA after Wii Fit training compared to TD children. However, this significant difference between groups was seen at both baseline and after Wii Fit training.

There was a decrease in the TUG score in two children with BI (Tatla et al. 2014) and in 20 children with developmental delay (Salem et al. 2012) after Wii Fit training. In addition, significantly greater improvements in SLST were seen in the Wii Fit group compared to the conventional rehabilitation group of children with developmental delay (Salem et al. 2012). Children with lower limb amputations demonstrated an increase in the CB&M score and a decrease in COP sway area during standing after Wii Fit training (Andrysek et al. 2012). In addition, children with trans-femoral amputations showed greater improvements than children with Van Ness amputations. This was because children with Van Ness amputations showed similar COP parameters to TD children. However, the sample consisted of six participants, which was too small to detect a significant difference.

In conclusion, the literature relating to the effects of Wii Fit games on balance for children with balance impairments is still limited. The studies found so far support the use of Wii Fit games and have shown positive significant improvements in balance measures. Although there was a lack of standardised training settings, intensity and game selection, it can be concluded that training with Wii Fit games in clinics or schools for 30 min three times a week for a period of four to six weeks is effective in improving dynamic balance among children aged between 6 and 16. Even though the body of literature relating to the effectiveness of Wii Fit for balance is still growing, these studies all inform about the potential effect of Wii Fit games on balance.

Table 3.11: Studies tested the effect of Wii Fit balance games on children with limited balance

Study	Sample	Groups	Wii Fit training	Assessments	Results
Mombarg et al. 2013	n=29 Children with poor motor performance aged 7-12 y/o	2 groups; 1- Wii Fit n=15 2- Control n=14	30 min, 3/week for 6 weeks, 18 balance games [3-5 games/session], School setting	Before and after training with; MABC-2 [motor coordination], and BOT-2 [balance, speed and agility]	Wii Fit group showed significant increase in only the balance part scores of both measures
Jelsma et al. 2014	n= 28 Children with P-DCD aged 6-12 y/o n= 20 matching TD children	2 groups [n=14 each]; 1- Wii Fit 2- No intervention then Wii Fit	30 min, 3/week for 6 weeks, 18 balance games [child choice], school setting	Before and after training with; MABC-2, BOT-2 [balance], Ski slalom game score, Enjoyment scale	Significant improvement in balance scores of MABC-2 and BOT-2 following Wii Fit training phase for both groups, which was significantly greater than control phase
Ferguson et al. 2013	n=46 Children with DCD aged 6-10 y/o	2 groups {not randomized, from three schools}; 1- NTT n=27 2- Wii Fit n=19	30 min, 3/week for 6 weeks, 13 Wii Fit games, school setting NTT {out-doors}; 45-60 min, 2/week, 9 weeks	Before and after training by blinded assessor with; MABC-2, FSM, HHD, MPST, 20mSRT	NTT group show significant grater improvement than Wii Fit group in motor performance, functional strength and cardio-respiratory fitness. Significant balance improvements after training in both groups
Hammond et al. 2014	n=18 Children with DCD aged 7-10 y/o	2 groups; 1- Wii Fit-control [jump ahead] n=10 2- Control [jump ahead -Wii Fit n=8	10 min, 3/week for 4 weeks, 9 balance games, School setting Jump ahead; 1hour/week, 4 weeks	Before and after training phase 1 [week 4] then phase 2 [week 18] with; BOT-2 [balance], CSQ, SDQ	Significant improvements in BOT-2 totals scores following Wii fit phase only for both groups
Abdel-Rahman 2010	n=30 Children with Down syndrome aged 10-13 y/o	2 groups {n=15 each}; 1- Wii Fit 2- Control	30 min, 2/week for 6 weeks plus therapy, 3 Wii Fit balance games, clinical settings	Before and after training with; The balance subtest of BOT-2	Wii fit group showed higher significant difference in balance between pre- & post- training

Salem et al. 2012	n= 40 Children with develop-mental delay aged 3-5 y/o	2 groups {n=20 each}; 1- Wii 2- Traditional rehabilitation	30 min, 2/week for 10 weeks, 3 balance games, 3 aerobics games, 2 strengthening games, 3 Wii Sports games, clinical settings	before and after training by blinded assessor with; 10MWT, TUG, SLST, 5 times STST, TUD, 2MWT, Grip strength, GMFM-88 only D & E	Significant improvements in all outcomes after training for both groups. But, Wii group showed significant grater improvement in grip strength and single leg stand test, compared to control
Andrysek et al. 2012	n= 6 Children with unilateral lower limb amputation aged 8-18 y/o	3 TF 3 VN 10 age match TD controls	20 min, 4/week for 4 weeks, 2 balance games, home settings	Before, after training [week 5] and follow up [week 13] by blinded assessor with; 1- COP area, maximum excursion and RMS 2- CB&M	Average decrease in COP sway area by 41%, and increase in CB&M scores of 1.2 points after training with Wii Fit. TF showed greater improvement than VN
Tatla et al. 2014	n=3 Children with TBI aged 12-14 y/o	-	30 min 5/week, [1:3 weeks, 2: 2days & 2 weeks, 3: 2 weeks], 9 balance games, Inpatients acute setting	Daily assessment by blinded assessor with; TUG, FRT, Wii Fit balance test, PMS, PEDI [only once a week]	Grater improvements for the two participants with longer Wii Fit training showed by a decrease in TUG, increase in FRT & PMS
Esposito et al. 2013	n= 71 children with MoA with mean age [9.1± 1.9] n=93 TD children with mean age [8.9±2]	2 group {different, not randomized}; 1- MoA, n=71 2- TD, n=93	30 min, 3/week, 12 weeks for both groups, 18 Wii fit games including 6 balance games, 3- 5/session, home settings	Before and after training with; MABC, and Beery visual-motor integration test	Significant differences between groups at baseline and after training. Only MoA children group showed significant improvements in all variables after Wii Fit training

2MWT= 2 Minute Walk Test, 10MWT= 10 Meter Walk Test, 20mSRT= 20 meter Shuttle Run Test, ABC= Agility, Balance and Coordination, BOT-2= Bruininks-Oseretsky test, CB&M= community balance and mobility scale, COP= Centre of Pressure, CSQ= Coordination Skills Questionnaire, DCD= Developmental Coordination Disorder, FSM= Functional Strength Measure, GMFM= Gross Motor Function Measure, HHD= Hand-Held Dynamometer, MABC-2 =Movement Assessment Battery for Children, FRT= Functional Reach Test, MoA= Migraine without Aura, MPST= Muscle Power Sprint Test, NTT= Neuromotor Task Training, P-DCD= Probable Developmental Coordination Disorder, PEDI= Paediatric Evaluation of Disability Index, PMS= Paediatric Motivation Scale, RMS= Root Mean Square, SDQ= Strengths and Difficulties Questionnaire, SLST= Single Leg Stance Test, STST= sit to stand test, TBI= Trumatic brain injury, TD= Typically Developed, TUD= Timed Up and Down stairs test, TF= Trans-Femoral amputation, TUG= Timed Up and Go, VN= Van-Ness amputation

3.4.2.2 Children with CP

Deutsch et al. (2008) published the first case report describing the feasibility of using the Wii in rehabilitation programmes. It showed positive outcomes in visual-perceptual processing, postural control and walking distance when the rehabilitation of an adolescent with CP was augmented with the Wii (Deutsch et al. 2008). The possibility of implementing the Wii in a rehabilitation setting for children with CP was first tested by Gordon et al. (2012), when the authors explored the potential impact of the Wii on the gross motor function of children with CP. The results showed significant changes in the GMFM score that exceeded the minimal clinically important difference [MCID] for the scale. However, these changes were not statistically significant due to the small sample size of seven children with CP. Both studies examined the use of Wii Sports with a CP population and thus provide the basis for the feasibility and acceptability of using Wii games in the rehabilitation of children with CP.

The literature related to using Wii games for children with CP is limited in general, and the specific literature that includes Wii Fit games in balance rehabilitation for children with CP is even more limited. Therefore, only four studies were found (Ramstrand & Lygnegård 2012; Sharan et al. 2012; Jelsma et al. 2013; Tarakci et al. 2013). These studies will be discussed in relation to the study design and sample, the Wii Fit training, the outcome measures used and the main results. Table 3.12 gives a brief summary of the studies' details and main findings.

3.4.2.2.1 Study design and sample

Each of the four studies had a different research design: randomised cross-over (Ramstrand & Lygnegård 2012), one group pre- and post-test (Tarakci et al. 2013), two groups pre- and post-test, including a control group (Sharan et al. 2012) and multiple single-subject blinded with multiple baselines (Jelsma et al. 2013). However, none of the studies included an RCT due to the limited numbers in the targeted population and the exploratory nature of the research.

The sample size in each study was less than 20 children, with no power calculation. In addition, two studies reported a drop out rate of about 40% (Ramstrand & Lygnegård 2012; Tarakci et al. 2013). Therefore, the results of these studies were based on a limited number of children with CP aged between 8 and 14. This affected the statistical significance and the generalisability of the results.

Children in all studies were between the ages of 5 and 17. Three studies included children with GMFCS level I-III (Ramstrand & Lygnegård 2012; Sharan et al. 2012; Jelsma et al. 2013; Tarakci et al. 2013). However, there was only one participant in one study who was at GMFCS level III (Tarakci et al. 2013). This means that results are specific to children with CP at GMFCS level I-II only. Sharan et al. (2012) included children with CP who were postoperative without any information about the type of operation or their functional levels. In this case, the study results could not be interpretive or generalisable to children with CP.

3.4.2.2.2 Wii Fit training and settings

The Wii Fit training intensity plays a major role in the differences between studies. As mentioned earlier, most studies used Wii Fit games for 30 min per session 2–3 days per week for a period of 4–6 weeks. Studies performed on children with CP had about the same intensity, but two studies were for 3 weeks (Sharan et al. 2012; Jelsma et al. 2013) and one study was for 12 weeks (Tarakci et al. 2013). All three studies demonstrated significant dynamic balance improvements.

All studies used only Wii Fit balance games, except Sharan et al. (2012), who used Wii Fit and Wii Sports games. This means that not only Wii Fit balance games can improve balance but so can all Wii Fit games or Wii Sports and Wii Fit games together. This may be due to the nature of the games that encourage the use of the whole body movement whether standing on a board to shift weight or standing on the floor with freedom of movement. The differences between Wii Fit balance games and Wii Sports games may need to be tested as it could be that Wii Fit balance games train for static balance and Wii Sports games train for dynamic balance.

Two studies used Wii Fit games in a therapy session (Jelsma et al. 2013; Tarakci et al. 2013), while Ramstrand & Lygnegard (2012) used Wii Fit games as home exercise. As mentioned earlier, school settings might be useful for children; however, the number of children with CP in each school is limited. Therefore, clinical settings are more convenient for children with CP and their families. Although the Wii Fit is portable and can be used in different settings, no significant improvements were found when it was used at home (Ramstrand &

Lygnegård 2012). This may be due to the lack of supervision of Wii Fit training, as games may or may not have been played by the children with CP, and even if they were the WBB may have been manipulated to get high scores. On the other hand, when children with CP played Wii Fit games at therapy sessions with therapist supervision, significant clinical improvements were seen. This may be because the therapist focuses on the quality of movement instead of just monitoring the playing of a game or emphasising a high score. Therefore, supervision by a therapist while playing Wii Fit games is recommended for children with CP.

3.4.2.2.3 Outcome measures and results

Only in the study by Ramstrand and Lygnegard (2012) was a laboratory force platform used to measure balance. This study found no significant difference in COP velocity between before training with Wii Fit and after training with Wii Fit. Although other sophisticated measures were used for reactive balance and weight shift, there were no other functional measures of dynamic balance to test the clinical effect. This may suggest that the effect of Wii Fit training on balance may not be detected with laboratory testing equipment that shows significant differences. However, when testing balance activity using functional measures, some improvement may be reflected.

Looking at the other three studies (Sharan et al. 2012; Jelsma et al. 2013; Tarakci et al. 2013), it can be seen that significant improvements were found because functional outcome measures were used. However, each study used different measures. Some functional measures, such as the BOT-2, the SLST, the TUG and the FRT, which were used by Jelsma et al. (2013) and Tarakci et al. (2013), detected significant improvements in balance. However, these measures are subject to assessor bias; only one study used a blinded assessor (Jelsma et al. 2013). There were medium improvements in the BOT-2 balance scores after the Wii Fit training phase; assessments were conducted once a week for nine weeks, which means that there was a practice and learning effect of the repeated measures. In addition, Tarakci et al. (2013) used Wii Fit gaming scores and balance tests as outcome measures, which are not reliable, (Gras et al. 2009; Wikstrom 2012) or recommended and do not reflect the effect of games on functional balance.

Each of the four studies was conducted in a different country. While demographic and cultural differences may not impact children with CP, each country's health system may impact their rehabilitation. For example, children with CP in a developed country like

Sweden may have received more therapy training in the community and at school compared to children with CP in a developing country like South Africa. This may be an indirect factor in the effect of Wii Fit games, as children with CP in a developed country may have a higher functional level where Wii Fit games did not show any improvement. Therefore, this could be the reason Wii Fit games did not induce significant balance improvements in the study by Ramstrand and Lygnegard (2012) conducted in Sweden but did induce significant clinical improvements in three studies from the developing countries of South Africa (Jelsma et al. 2013), India (Sharan et al. 2012) and Turkey (Tarakci et al. 2013).

In summary, using the Wii Fit balance games in paediatric rehabilitation was introduced less than five years ago. Therefore, the literature relating to its effectiveness in terms of balance for children with CP specifically is still limited. The literature far agrees on the positive effect of Wii Fit balance games in clinical settings assessed using functional measures. However, without a randomised control group it is hard to be sure that this improvement is the effect of Wii Fit games. In addition, as expressed earlier, the small non-power sample of all studies cannot provide statistically significant results. Furthermore, the homogeneity of the sample makes the results limited to children with CP of a specific age range and functional level. However, these studies highlighted the need for a larger sample in a RCT to identify the effect of Wii Fit training on balance for children with CP.

Table 3.12: Studies tested the effect of Wii Fit balance games on children with CP

Study	Sample	Groups	Wii Fit training	Outcome measures	Results
Ramstrand & Lygnegard 2012	n=16 [4 drop out] Children with CP, GMFCS I-II, aged 8-17 y/o	2 groups {n=8 each}; 1- Wii Fit- no training 2- No training-Wii Fit	30 min, 5/week for 5 weeks, 6 balance games, home settings	Before, after phase 1[week 5] and after phase 2 [week 10] with; 1- SOT for COP velocity 2- Reactive balance by muscular EMG 3- Rhythmic weight shift	No significant improvements in any of the outcome measures after Wii Fit training
Tarakci et al. 2013	n=19 [5 drop out] Children with CP, GMFCS I-III, aged 5-17 y/o	One group	40 min, 2/week for 12 weeks, 4 balance games, clinical settings	Before and after training with; SLST, TUG, 6MWT, FRT, Wii Fit test and game scores	Significant improvement in all outcome measures following Wii Fit balance training
Sharan et al. 2012	n=16 postoperative children with CP with mean age 8.8 ± 3.2	2 groups {n=8 each}; 1- Wii training **2-** Control	3/week for 3 weeks, Wii Fit & Wii Sport games	Before and after training with; MACS, PBS	Significant improvement in PBS and MACS for both groups. Grater improvements of PBS seen in Wii group
Jelsma et al. 2013	n=14 children with CP, GMFCS I-II, aged 7-14 y/o	-	25 min, 4/week for 3 weeks, 6 balance games, clinical settings	Once a week for 9 weeks by blinded assessor with; BOT-2 [Balance and RSA subtests], TUDS	Significant improvement in balance scores after Wii Fit phase. However improvements in RSA & TUD were not significant

6MWT= 6 Minute Walk Test, BOT-2= Bruininks–Oserestky test of Motor Performance 2, CP= cerebral palsy, COP= Centre of Pressure, FRT= Functional Reach, MACS= Manual Ability Classification System, PBS= Paediatric Balance Scale, RSA= Running speed and agility, SLST= Single Leg Stance Test, SOT= Sensory Organisation Test, TUDS= Timed Up and Down stairs, TUG= Timed Up and Go

3.5 Summary of literature

The Nintendo Wii is an enjoyable active video game system that can be played by all family members of different ages. The Wii Fit games with the WBB were specifically designed to increase physical activity while playing. The Wii Fit games include games that aim to improve balance and increase endurance and strength, and the WBB as a tool gives good visual feedback about movements. In addition, this over the shelf game is cost effective, portable, and contain high technology making it a convenient tool to be used in clinical rehabilitation. Therefore, some researchers are interested in investigate the effect of Wii Fit training, specifically balance, in rehabilitation. Other researchers have focused on the accuracy of the WBB's data to detect changes in standing postural control to determine if it is a suitable balance assessment tool.

Therefore, the literature relating to the use of Wii Fit games for balance training or the use of the WBB for balance assessment has grown from 2010 until today. Following a systematic database literature search and selection process based on inclusion and exclusion criteria, a total of 74 studies were reviewed in this chapter. 22 studies investigated the use of the WBB or Wii Fit in balance assessment, and 52 studies investigated the effect of Wii Fit balance games in training to improve balance for different rehabilitation populations.

3.5.1 Summary of the literature relating to the WBB as a balance assessment tool

Twelve studies agreed that the WBB's COP data are valid and comparable to data obtained from laboratory force plates (Clark et al. 2010; Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Holmes et al. 2013b; Larsen et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Abujaber et al. 2015; Pavan et al. 2015), the Smart Balance Master (Chang et al. 2013) and the baropodometer platform (Sgrò et al. 2014). In addition, the COP data obtained from the WBB showed significant moderate correlation with the performance of clinical functional balance tests, such as the FRT (Bower et al. 2014). Seven of these studies showed excellent test re-test reliability of COP data from the WBB along with the validity results (Clark et al. 2010; Chang et al. 2013; Bower et al. 2014; Larsen et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Abujaber et al. 2015). The

WBB's WBA data obtained while standing on two WBBs has been shown to be reliable with or without visual feedback (Clark et al. 2011), and the WBB can reliably assess balance in adults with impaired vision (Jeter et al. 2015).

The COP parameters calculated based on data obtained from the WBB were COP path length, COP velocity and Max COP sway in the AP and ML directions. In addition, other postural control outcomes were calculated, such as WBA (Clark et al. 2011; Bower et al. 2014) and the vGRF (Yamamoto & Matsuzawa 2013; Abujaber et al. 2015). These outcomes were calculated using connecting software that was different in each study. However, the calibration process used to extract the COP data from the WBB was that suggested by Clark et al. (2010), who were the first to test the reliability and validity of the COP path length obtained by the WBB.

Static double-leg or single-leg standing with eyes open and closed were the main four balance tasks used in most of the studies. Other studies tested dynamic standing tasks, such as sit-to-stand (Bower et al. 2014; Abujaber et al. 2015), squatting (Clark et al. 2011) and jumping (Yamamoto & Matsuzawa 2013). This shows the sensitivity of the WBB to quantify COP trajectory accurately during a variety of standing tasks.

Other researchers looked at different ways of using the WBB technology. Four studies used the COP parameters detected by the WBB to address different therapeutic purposes, such as predicting falls (Kwok et al. 2015), predicting a suitable walking aid (Pua et al. 2015), assessing sleepiness (Tietäväinen et al. 2013) and detecting postural changes with different visual tasks (Koslucher et al. 2012). Although these four studies did not aim to test the reliability or validity of the WBB measures, they highlighted the extra benefits of WBB to inform clinical practice in prescribing suitable walking aids and predicting falls.

There has been confusion between data obtained from the WBB for balance assessment and using the WBB with the Wii Fit to measure balance either based on Wii Fit game scores or balance test scores. The WBB, as a separate tool, can provide valid and reliable standing postural control outcomes. However, when it is connected to the Wii Fit, it gives feedback about movements during game play, which is useful for training purposes. In addition, the WBB data is used to calculate Wii Fit game or test scores, which usually refer to the targets met by the player in each game or test. Therefore, the Wii Fit game scores showed poor reliability and concurrent validity (Wikstrom 2012), and improvements in Wii Fit game scores are highly specific to the Wii gaming device (Naumann et al. 2015). In addition, the

Wii Fit balance tests have been shown to be unreliable (Gras et al. 2009) and do not correlate with clinical functional standardised tests of balance, mobility or fitness (Reed-Jones et al. 2012b). Accordingly, when the Wii Fit games are used as intervention for balance training, the Wii Fit game scores or test should not be used as an objective outcome measure of balance. Instead, the WBB can be used an assessment tool on its own and can provide valid and reliable data for standing postural control outcomes.

The literature relating to the use of the WBB as a balance assessment tool was limited to six studies between the years 2010 and 2012. At that time, there was a gap in the literature in terms of validity and reliability reports on WBB data. In addition, there has been limited explanation of the WBB technology and how to calibrate the WBB. Therefore, the present study aimed to first understand the WBB calibration process in order to use the WBB as a balance measure later in the study. However, the number of published research papers appearing between 2013 and 2015 has increased to 16 studies. It can be seen that with time, more and more researchers have gained a better understanding of how the WBB works, and the gap has been filled. However, most of these studies were based on testing standing balance among young and old healthy adults; only a few tested patient populations, such as adults with total joint arthroplasty (Abujaber et al. 2015), adults with PD (Holmes et al. 2013b) and adults post stroke (Bower et al. 2014).

In addition, there is limited research regarding the use of the WBB to assess balance for the child population. Only recently, Larsen et al. (2014) showed that the WBB is a valid and reliable tool to assess balance in TD children. To the best of the author’s knowledge, thus far, the effectiveness of the WBB to measure postural control and COP path length among children with CP has not been verified. This means that there is a gap in the literature in terms of using the WBB for children with CP and in terms of how feasible it is to use in clinical practice. Therefore, this study aimed to test the reliability of the WBB’s COP data for TD children and children with CP. This is for using the COP data from the WBB as an outcome measure of balance to test the effect of Wii Fit balance games training for children with CP.

3.5.2 Summary of the literature relating to Wii Fit balance games as balance intervention tools

3.5.2.1 Adult population

The literature relating to using the Wii Fit as a balance rehabilitation intervention was spread across adults with balance disturbances affected by aging , musculoskeletal injury or surgery, neurological deficits or injury or vestibular loss. The studies found in the literature were conducted with older adults, post knee surgery patients, stroke survivors, adults with PD, adults affected by TBI and adults experiencing vestibular loss. A summary of the main findings for each population is listed below.

3.5.2.1.1 Older adults {balance reduced by age}

The highest number of studies conducted with older adults found in the literature was 15. The findings showed significant increases in the BBS score after training (Williams et al. 2011; Chao et al. 2013). In addition, there were significant improvements in the TUG test and the ABCS (Rendon et al. 2012), with a decrease in COP area (Cho et al. 2014) in the Wii Fit group compared to a control group with no training. When comparing Wii Fit to any other forms of balance training, the results were conflicting, as four studies showed no significant differences between groups. However, significant improvements after training in both groups was seen in terms of the TUG test, the Ten Step test and the postural sway index (Singh et al. 2013), BBS and the Tinetti test (Padala et al. 2012), the ABCS (Singh et al. 2012) and dynamic balance reactions assessed using a dynamic motion analysis system (Pluchino et al. 2012). This means that Wii Fit training is not superior to any other form of balance training and that it showed effective results after training. In contrast, three studies found significant balance improvements favouring the Wii Fit training group compared to the other groups in terms of the BBS (Williams et al. 2010; Laver et al. 2012), the TUG test (Laver et al. 2012) and the performance of obstacle course (Reed-Jones et al. 2012a). Two studies indicated that when the Wii Fit training is mixed with physical activity or physiotherapy, it results in more significant changes in the BBS (Bateni 2012), the Tinetti test and the Unipedal test (Toulotte et al. 2012).

3.5.2.1.2 Post knee surgery patients {balance affected by musculoskeletal injury}

Four studies used Wii Fit games as a form of rehabilitation for adults following knee surgery (Fung et al. 2012; Baltaci et al. 2013; Sims et al. 2013; Puh et al. 2014). Postural outcomes of COP were collected through laboratory systems. The main positive significant balance improvements were seen in terms of 1) increased reach while standing on a single leg (Baltaci et al. 2013; Sims et al. 2013), 2) decreased COP sway during single-leg standing with eyes open and closed (Sims et al. 2013) on firm and foam surfaces (Puh et al. 2014) and 3) symmetrical body weight distribution during double-leg standing (Puh et al. 2014). However, all studies showed no significant differences between groups.

3.5.2.1.3 Adults with stroke {balance affected by neurological deficits}

Nine studies used Wii Fit games in the rehabilitation of balance for stroke patients. The results were contradictory. Three studies agreed that there were no differences between groups, as both showed positive significant improvements after training in dynamic balance in terms of the BBS, the TUG test and FRT and in static balance in terms of COP sway and the stability index (Barcala et al. 2013; Hung et al. 2014; Yatar & Yildirim 2015). In contrast, Cho et al. (2012) and Morone et al. (2014) both claim that significant changes were observed in the Barthel index disability level, the BBS and the TUG test in the Wii Fit group. In addition, the Wii Fit training increases corticomotor excitability in the paretic limb for more inter-hemispheric symmetry (Omiyale et al. 2015). Balance improvements were not maintained at any of the follow-up assessments (Deutsch et al. 2009; Hung et al. 2014; Yatar & Yildirim 2015), except for one study that showed the maintenance of improvements after one month of Wii Fit training (Morone et al. 2014). There was a high level of enjoyment expressed, but the Wii Fit training is not recommended for home exercise as it requires supervision for adults post stroke.

3.5.2.1.4 Adults with PD {balance affected by neurological deficits}

Seven studies investigated the effect of Wii Fit games on balance for adults with PD. The studies included either one group of adults with PD or two groups comparing adults with PD to healthy controls; only one compared between two groups of adults with PD. Results from all studies showed significant improvements in functional balance outcome measures, mainly in terms of the BBS (Zettergren et al. 2011; Loureiro et al. 2012; Pompeu et al. 2012; Mhatre et al. 2013), the TUG test (Zettergren et al. 2011; Esculier et al. 2012), time spent during single-leg standing (Esculier et al. 2012; Pompeu et al. 2012) and in gait measures (Zettergren et al. 2011; Esculier et al. 2012; Mhatre et al. 2013) after Wii Fit training. However, there were no significant improvements in static standing balance assessed by COP length or velocity (Holmes et al. 2013a).

3.5.2.1.5 Adults with TBI {balance affected by neurological deficits}

The literature relating to Wii Fit games to train balance for BI survivors is limited to two feasibility studies. The results from both studies showed positive significant changes after Wii Fit training in terms of the BBS (Cuthbert et al. 2014), the 6MWT (McClanachan et al. 2013) and gait speed (McClanachan et al. 2013; Cuthbert et al. 2014). These changes exceeded the minimum clinical importance difference threshold for each measure. However, neither study found any significant differences between groups.

3.5.2.1.6 Adults with vestibular disorder {balance affected by vestibular loss}

Two studies investigated the feasibility and effectiveness of including Wii Fit games as part of vestibular rehabilitation. One was an RCT and the other was a cohort study. The sample size was powered and similar in both studies. The main outcome measures used in both studies were related to nystagmus, gait speed and Dynamic Gait Index. The only balance measure used in both studies was the SOT, which is a system assessing stability in different sensory conditions. However, there were neither clinical functional assessments of balance like the BBS used nor laboratory static standing COP measures. Sparrer et al. (2013) highlighted the effectiveness of Wii Fit training as the absence of nystagmus 2.1 days earlier in the Wii Fit group compared to the placebo group. Both studies showed balance improvements in the SOT after training; however, this improvement was only significant in the Wii Fit group when compared to placebo group (Sparrer et al. 2013). When the Wii Fit training was used in vestibular rehabilitation, the differences between groups were not significant (Meldrum et al. 2015). Three adverse events were reported by Meldrum et al. (2015), which calls into question the safety of Wii Fit home training.

Overall, more studies were conducted with adults experiencing limited balance ability due to different factors. The results of most studies showed positive significant results. The effect of the Wii Fit games was seen in significant improvements in clinical functional balance tests such as the BBS, the TUG test and FRT. A smaller number of studies showed significant changes in the COP parameters during static standing after the Wii Fit training.

In addition, most studies agreed that the Wii Fit training has an effect equal to conventional rehabilitation, lower limb exercises or balance exercises. It was shown to be more effective when used together with other rehabilitation interventions.

These studies were reviewed and discussed because of the limited research on children. In addition, they provided more information about the different types of effects of Wii Fit games. These effects can explain how Wii Fit can improve balance. For example, older adults with a high risk of falling showed greater performance in the obstacle course when trained with the Wii Fit (Reed-Jones et al. 2012a). This was due to the nature of the Wii Fit training, which involves weight shifting training with visual feedback.

The discussed studies point out the mechanical effect, sensory effect, neurological effect, vestibular effect, learning effect and cognitive effect associated with Wii Fit. Adults post anterior or posterior cruciate ligament reconstruction or with a history of lower limb injury showed significant improvements in single-leg standing with eyes closed or on a foam surface (Baltaci et al. 2013; Sims et al. 2013; Puh et al. 2014). This points to the effect of Wii Fit training on standing balance by increasing the joint proprioception sensation, which is due to the weight shifting requirements of Wii Fit games that increase the sense of load on joints. This highlighted the mechanical and sensory effect of Wii Fit training.

The weight shifting training of the Wii Fit games has led to more symmetrical weight bearing and more weight applied on the paretic limb in stroke patients. This was shown by the increase in paretic limb corticomotor excitability, which increases the inter-hemispheric symmetry in adults post stroke (Omiyale et al. 2015). This highlights the neurological effect of the Wii Fit games. Wii Fit training decreases hospitalisation for adults with UVL by the earlier absence of nystagmus (Sparrer et al. 2013) and improves stability when experiencing different sensory conditions of SOT (Sparrer et al. 2013; Meldrum et al. 2015). This shows the vestibular effect of Wii Fit games.

The learning curve and learning deficits were identified among adults with PD while playing three Wii Fit games that required fast decision making and fast movements to avoid virtual obstacles. However, adults with PD demonstrated a transfer of learning from the games to a motor task that was not trained, specifically FRT (Mendes et al. 2012). This emphasises the learning effect of training with Wii Fit games and how it can be transferred to motor tasks other than those use in the games. Mendes et al. (2012) selected Wii Fit games that include cognitive demands, such as attention, planning and decision making. Adults with PD have demonstrated improvements in game scores after training, similar to healthy controls. Furthermore, the Montreal Cognitive Assessment showed significant improvements immediately after Wii Fit training for adults with PD that were maintained for two months (Pompeu et al. 2012). This shows the cognitive effect of the Wii Fit games training.

3.5.2.2 Children population

There were only 13 studies in the literature that investigated the effect of Wii Fit balance training on children with impaired balance due to different diagnoses, such as DCD (Ferguson et al. 2013; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014), DS (Abdel-Rahman 2010), developmental delay (Salem et al. 2012), lower limb amputations (Andrysek et al. 2012), TBI (Tatla et al. 2014), MoA (Esposito et al. 2013) and CP (Ramstrand & Lygnegård 2012; Sharan et al. 2012; Jelsma et al. 2013; Tarakci et al. 2013).

The accumulated results from these studies showed significantly greater increases in the balance subtests or the total scores of the MABC-2 and the BOT-2 when compared to no training for children with DCD (Ferguson et al. 2013; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014), DS (Abdel-Rahman 2010) and MoA (Esposito et al. 2013). There was a decrease in the TUG test results for two children with TBI (Tatla et al. 2014) and for 20 children with developmental delay (Salem et al. 2012) after Wii Fit training. In addition, significantly greater improvements in SLST were seen in the Wii Fit group compared to the conventional rehabilitation group of children with developmental delay (Salem et al. 2012). Children with lower limb amputations demonstrated an increase in the CB&M score and a decrease in COP sway area during standing after Wii Fit training (Andrysek et al. 2012).

Children with CP in specific showed no significant improvements in any of the laboratory outcomes of balance, including COP velocity, muscular EMG or rhythmic weight shifting after five weeks of home Wii Fit training (Ramstrand & Lygnegård 2012). However, significant improvements were observed in functional balance assessments, such as SLST, TUG, FRT and 6MWT following 12 weeks of Wii Fit training (Tarakci et al. 2013) in addition to significant improvements in the Paediatric Balance Scale [PBS] and the Manual Ability Classification System [MACS] after 3 weeks of Wii Sports with Wii Fit training (Sharan et al. 2012). Furthermore, the balance scores of the BOT-2 increased significantly after 3 weeks of Wii Fit intervention (Jelsma et al. 2013).

The Wii Fit balance games were used as balance training tools because they possess the potential effectiveness of the virtual reality element and the games require players to shift weight while playing. Jelsma et al. (2013) suggested that balance improvements shown in children with CP could be attributed to the task-specific training of Wii Fit. Moreover, Hornby et al. (2011) found that an adequate amount of task-specific training can facilitate the plasticity of neuromuscular systems, which may lead to functional improvements. When considering weight-shifting practice as a task-specific practice, standing balance can be improved (Hartveld & Hegarty 1996). In addition, decreased COP sway area following Wii Fit training for children with lower limb amputations (Andrysek et al. 2012) shows the mechanical effect of Wii Fit games. Furthermore, because Wii Fit games are played in a standing position, they stimulate different trunk muscles, thereby increasing standing stability.

There is a gap between the research that demonstrated the effect of balance training for children with CP and the research that showed the effect of Wii gaming as a virtual reality in the rehabilitation of children with CP. However, some studies were found that closed this gap but not completely, as none of had a randomised control group to show the pure effect of the Wii Fit games. In addition, the small non-power sample size and the homogeneity of the sample limits the generalisability of the results. Moreover, the effect of Wii Fit games on static and dynamic balance for children with CP needs to be tested by both laboratory outcome measures and functional clinical balance outcome measures together. To the author’s knowledge, there is no study yet that has tested the effect of Wii Fit games on both static and dynamic balance for children with CP.

Therefore, a larger powered sample for an RCT is needed to identify the effect of Wii Fit training on balance for children with CP. This study was designed to be a methodological feasibility study, which can inform about the suitability of the methods and procedures for a future RCT. This study focuses on using both the WBB as a balance assessment tool and the use of Wii Fit games as balance rehabilitation tools for children with CP. Therefore, this study will investigate the WBB and its COP length reliability among children with and without CP. This will be further discussed in Chapters 4, 5 and 6. The main feasibility study will give preliminary findings about the effect of Wii Fit training on balance for children with CP.

Chapter 4: Developmental work on the validity of software communication with WBB

4.1 Introduction

The ability of the WBB to detect changes in the weight distribution of a player while playing a game indicates the potential of its sensors to assess the force distribution on the board and detect the resultant COP parameters of the standing player. This indicates the similarity between a WBB and a laboratory force plate and the possibility of using the WBB to assess standing balance. However, force plates have been specifically designed to assess balance and they use specific communicating software. In contrast, the WBB was initially designed to communicate with the Wii console to play only games. Nevertheless, researchers are interested in determining the effectiveness of the WBB as an assessment tool of balance that can be used both clinically and for research purposes.

If WBB can communicate with the Wii console through Bluetooth, then it can communicate with any computer that has the appropriate software and configuration to use the data. The chosen software should be able to extract data from the WBB sensors in a chosen frequency [Hz] and duration [seconds], and subsequently use that data for calculating the resultant COP [x, y] coordinates. The COP parameters, which include both distance and time, such as mean velocity or COP length, can then be calculated. In this manner, extant studies have used quantitative COP parameters to assess balance.

Studies in literature have shown the WBB to be a valid and reliable outcome measure of balance (section 3.3.1). Although software and outcomes were different across the studies, the calibration protocol used by all of them was the one suggested by Clark et al. (2010). This is because Clark et al. (2010) were the first to compare the validity and reliability of the COP path length obtained by the WBB with the COP path length collected from a laboratory force plate. Details of the calibration of the WBB and calculation of the COP are presented in Appendix 1. Therefore, before using the WBB to measure balance, or test its reliability, a software application must be chosen, designed and tested.

The communicating software of the WBB will need to have access to the WBB sensors through Bluetooth and the open source library [WiimoteLib]. Subsequently, it should be programmed using a calibration protocol (Appendix 1) to reset the calibration factors of each sensor. Moreover, the software should be programmed with a list of mathematical calculations to provide the COP coordinates, which are used to further calculate the COP path length. To assess the accuracy of the outcomes, known weights should be applied on the selected points of known coordinates. Therefore, this developmental work aims to test the validity of COP outcomes from the WBB using the chosen software. This is because the chosen software will also be used subsequently in the project, that is, during the reliability study, to assess the reliability of the WBB in assessing COP length with TD children and children with CP, then during the feasibility study where WBB will be used to assess standing balance among children with CP.

4.2 Aim

The aim of this developmental work is to assess the validity of two software programs, Stance© and MATLAB®, in providing accurate resultant COP [x, y] coordinates from the WBB.

4.3 Methods

This developmental work was to assess the validity of connecting software to the WBB to gain accurate resultant COP [x, y] coordinates. This was accomplished by applying static certified weights to marked points on the WBB and analysing the resultant data. It was a process in many steps; the results from each step led to the plan for the next one. Figure 4.1 shows the order of the seven steps with the question for each step. The setup, the procedures, and the analysis for all steps will be described generally, and then the findings and discussion for each step will be discussed separately.

4.3.1 Software

Clark et al. (2010) used LabVIEW as the connecting software to the WBB with a calibration program (Appendix 1). However, our research group was not familiar with LabVIEW. Therefore, different software were identified and Stance© was initially selected because of the following reasons: 1) it is a new software designed specially to communicate with the WBB, 2) it is user-friendly and practical and 3) it does not require any programming.

However, after conducting six different steps, errors were found and it was decided that Stance© would not be used. Following this, MATLAB® was chosen because it is a well-known software for designing algorithms; this software was programmed to detect data from the WBB and calculate the COP length. MATLAB® was tested in step seven. Therefore, this developmental work used two computer software programs to test the validity of the COP parameters from the WBB. To the best of the author's knowledge, no previously published study has used either of these software programs to measure COP parameters.

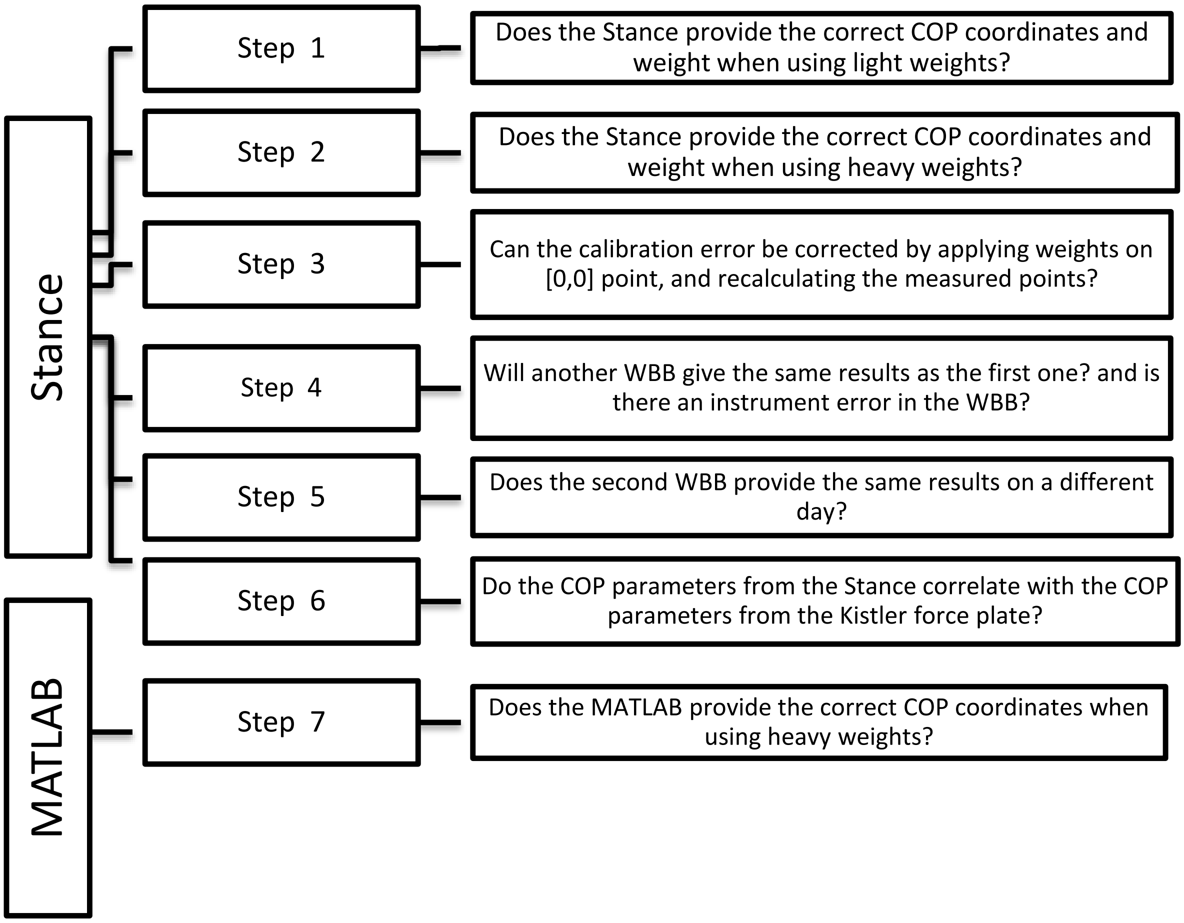


Figure 4.1: Diagram of the developmental work seven steps

4.3.1.1 Stance©

Stance© is a newly developed software designed by ETT s.r.l, which exploits the Nintendo WBB hardware to provide a balance assessment system. The WBB is connected with Stance© through Bluetooth. Once the subject's details are input and the duration of the test is decided, the output of COP movement is displayed in transverse and longitudinal planes according to time. Furthermore, a summary of the COP parameters {including the COP path length, sway area, and maximum laterolateral [LL] and AP oscillation} are displayed (Figure 4.2). These COP parameters are calculated on the basis of the row data extracted from the WBB's sensors. This row data is presented in a sheet of eight columns in the following manner: 1st column: acquisition instant, 2nd column: X value of COP, 3rd column: Y value of COP, 4th column: the total weight, 5th to 8th column: weight measured by each of the four sensors.

This software was designed to be user-friendly and practical for clinicians, therapists and researchers when assessing balance. It was developed based on the protocol in Clark et al. (2010); unlike the LabVIEW software used in Clark et al. (2010), Stance© does not need to be programmed with a set of equations to calculate COP coordinates. The calibration process based on the ETT Stance© manual was conducted by placing a known weight anywhere on the WBB and clicking for calibration (Appendix 2). This process was performed without providing any information about the amount or the location of weight placed.

To the author's knowledge, no previously published study has used Stance© in their measurements; therefore, the accuracy of the COP parameters from the WBB using Stance© needed to be tested before the software was used in the reliability study.

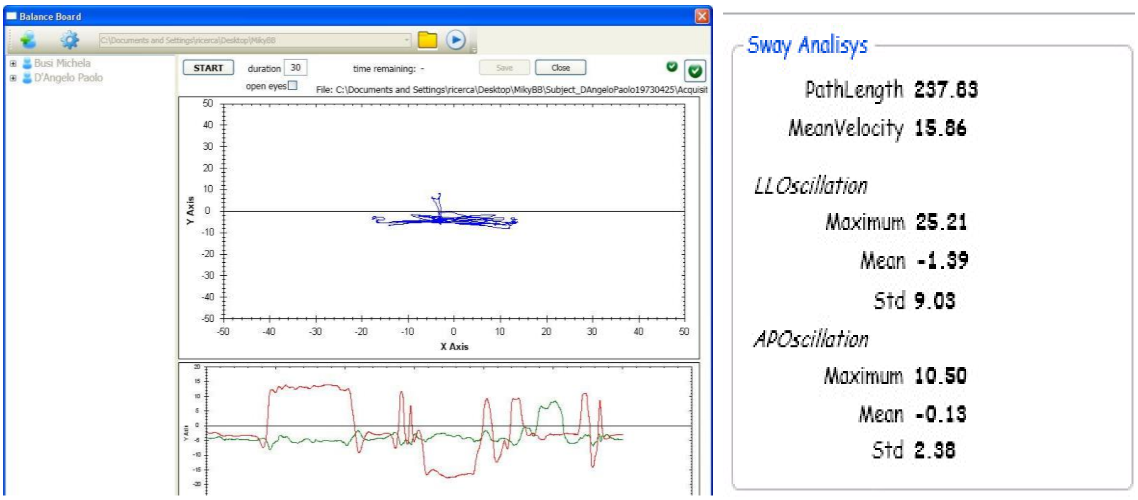


Figure 4.2: The Stance output and COP parameters

4.3.1.2 Matlab

MATLAB® is customised software with a high-level language for numerical computation. It can be used to analyse data, develop algorithms and create models. Its features enable it to be used for a range of applications, including signal processing, communications and measurement. MATLAB® can access data from files or other applications and can acquire data from external hardware devices for analysis and visualization (Mathworks 2012).

Dr. Stefan Bleeck and Dr. Gary Farrell from the Institute of Sound and Vibration Research [ISVR] at the Faculty of Engineering and Environment have programmed MATLAB® with math functions that calculate COP coordinates from each sensor of the WBB (Appendix 3). MATLAB® follows the math functions employed by Clark et al. (2010) with LabVIEW.

Although communication among the devices, computer and WBB was conducted through a Bluetooth dongle, an open source library [WiimoteLib] was required to enable MATLAB® to acquire data from the WBB (Figure 4.3). This library has been designed to enable communication between Wiimote and any computer software. Although the library has specifically been designed for the Wiimote, it can nevertheless be used for the WBB. Once the connection is successful, the calibration process starts. The calibration of WBB by MATLAB® comprises two steps. First, ‘calibration’ is clicked without applying any weight on the WBB. This is to identify the zero data of the WBB’s sensors before any weight is applied. Second, a specific weight [5 kg] is applied to the centre point of WBB and then ‘calibration’ is clicked again. A correction factor for each sensor is calculated, and these factors are added to the calculations of the COP coordinates. The frequency and duration of the test can be adjusted

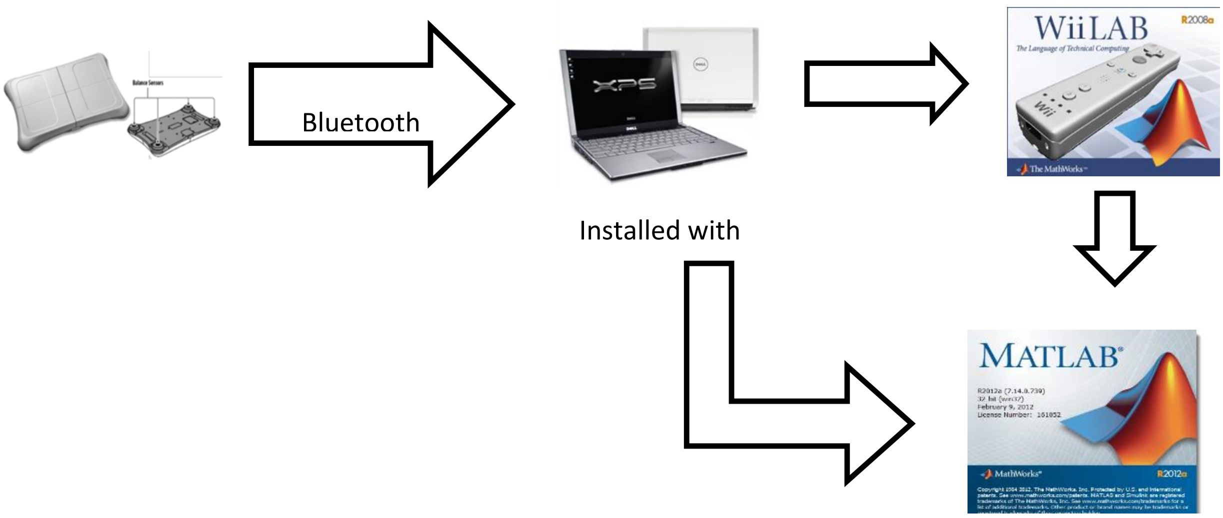


Figure 4.3: Communication process between WBB and MATLAB

4.3.2 Setup

The WBB was connected to a laptop [Windows XPS] through Bluetooth using a Bluetooth dongle (Figure 4.4). Stance© [ETT, s.r.l, 2010] and MATLAB® [R2011a] were installed on the laptop. An A3 grid sheet was placed and fixed on the WBB. Two fine lines that split the WBB into four quarters were highlighted on the grid sheet to represent the X and Y axes. Eight points were marked on the grid sheet: [9,6], [9,-6], [-9,6], [-9,-6], [16,9], [16,-9], [-16,9] and [-16,-9]. All the points were used as true COP points with known [X , Y] coordinates where known weights would be placed.

A tripod frame was designed especially for this testing to ensure that the weight applied to each known point would act on that specific point (Figure 4.5). The certified weights used varied from 2 kg to 40kg. The weight of the metal cylinder attached to the wooden plate, which was used to carry the weights, was measured; it weighed 439g. This weight was added to each of the known weights applied and was considered during comparison.

Figure 4.4 : Bluetooth dongle

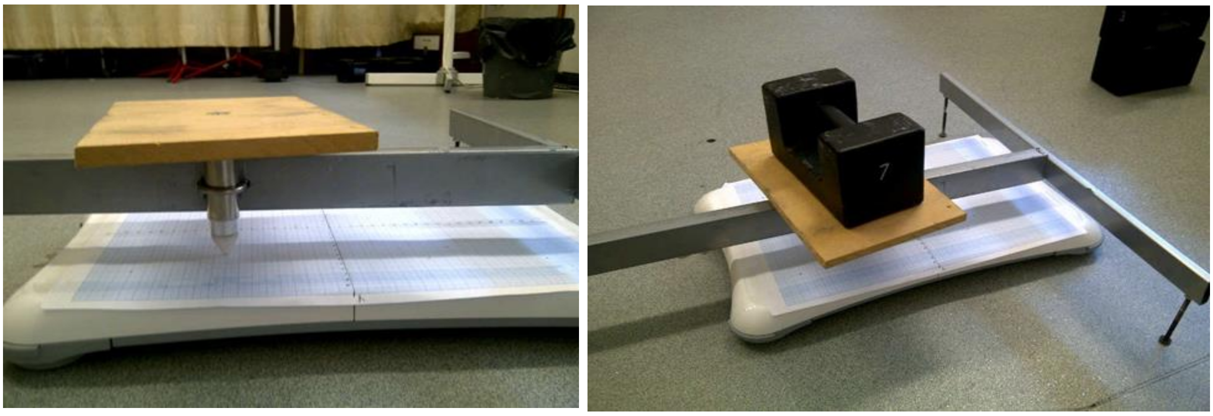


Figure 4.5: Tripod frame carrying weights to be applied on marked points

4.3.3 Procedures

The general procedure of all the steps following the setup was that a certified weight was placed on each of the eight points independently at each test and was recorded for one second. According to the software's frequency [100 Hz], each recording has 100 data points in one second. The procedures modified in each step will be explained with the findings of the respective step.

4.3.4 Analysis

Raw data captured by the software from the WBB was used for analysis. This data included weight on each sensor, total weight and resultant X and Y values, which are COP coordinates measured by the WBB. This raw data was copied to Microsoft Excel 2010; in the excel sheet, the mean weight and mean X and Y values were calculated for each recording. Subsequently, the measured data was compared to the true 'known' data. Both the measured and true data was plotted in tables and graphs with trend lines to determine the correlation between them.

In addition, grid graphs with marked true and measured points with each weight were used for visual compassion. To determine the distance between true point **[x, y]** and measured point **[x1,y1]**, the following Pythagoras calculation equation was used:

Distance between points = $\sqrt{\{(\boldsymbol{x}-\boldsymbol{x1})+(\boldsymbol{y}-\boldsymbol{y1})\}}^{2}$

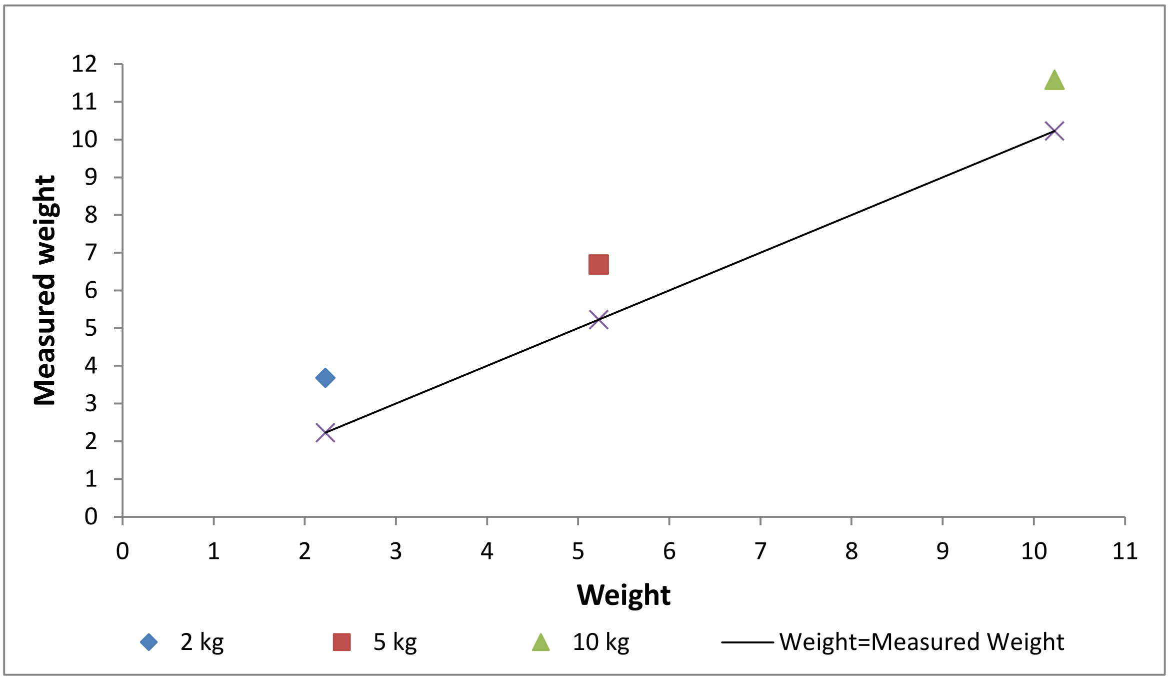
4.4 Findings and discussion of each step

4.4.1 Step one

A comparison of the weights measured with the certified weight applied (**Graph 4.1**) reveals that the weights measured were inaccurate; this may be because light weights {less than 10 kg} are not measured accurately by the WBB. Table A4.1 shows the values of COP coordinates separately for each point with each of the light weights (Appendix 4). The table clearly indicates that the measured values are not similar to true values. Graph A4.1 and Graph A4. 2 show the measured values of X and Y with each weight (Appendix 4).

It is evident that when the lightest weights [2 kg] were applied, the measured values were the farthest away from the true values. In addition, a trend relationship was seen between the weights and accurate measurements. For example, the higher the weight [10 kg] applied, the closer the measured value was to the true value of either X or Y. The WBB cannot accurately measure weights lighter than 10 kg. This means that the movements of children who weigh less than 10 kg will not be measured correctly by the WBB. This information is important when measuring children, who weigh lesser than adults, because although the WBB has a known upper limit of 150 kg (Nintendo 2008), the lower limit is unknown. Therefore, weights heavier than 10 kg need to be tested in the following step.

Graph 4.1: Step 1 weights and measured weights

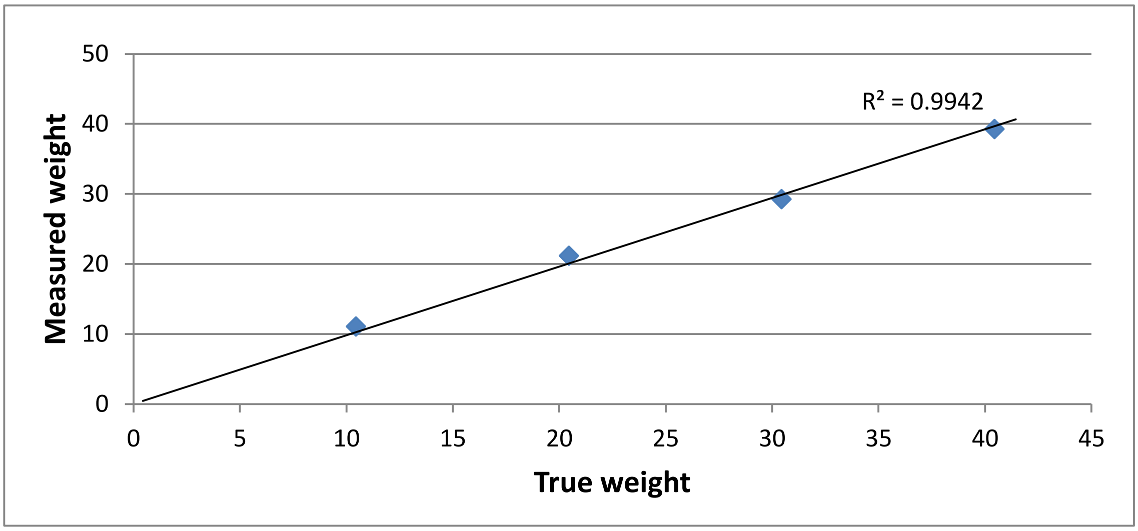


4.4.2 Step two

A comparison of the measured weights with the certified weights applied (Graph 4.2) shows that the measured weights were highly correlated with the true weights. This means that the WBB does measure heavy weights accurately. Table A4.2 shows the values of COP coordinates [x,y] separately for each point with each of the weights (Appendix 4). It can be seen that some values were the same as the true values, some were slightly different and others were significantly different from the true values. Graph A4. 3 and Graph A4. 4 show the measured values of X and Y with each weight (Appendix 4).

It is evident that the measured values were closer to the true values. This may be because heavy weights are measured more accurately than light weights by the WBB; therefore, the measured values of X and Y are close to their true values. However, the measured values with heavy weights {e.g., 40 kg} are not always closer to the true values. Furthermore, positive measured values were different from negative measured values in terms of their closeness to true values. This may be because the values of X and Y were displayed separately and not as coordinates of a measured point. Therefore, a grid graph was used for plotting the true points and measured points with each weight. **Graph 4.4** shows that the measured points were never the same or closer to true points. Measurements were fairly consistent with different weights.

Graph 4.2: Step 2 weights and measured weights

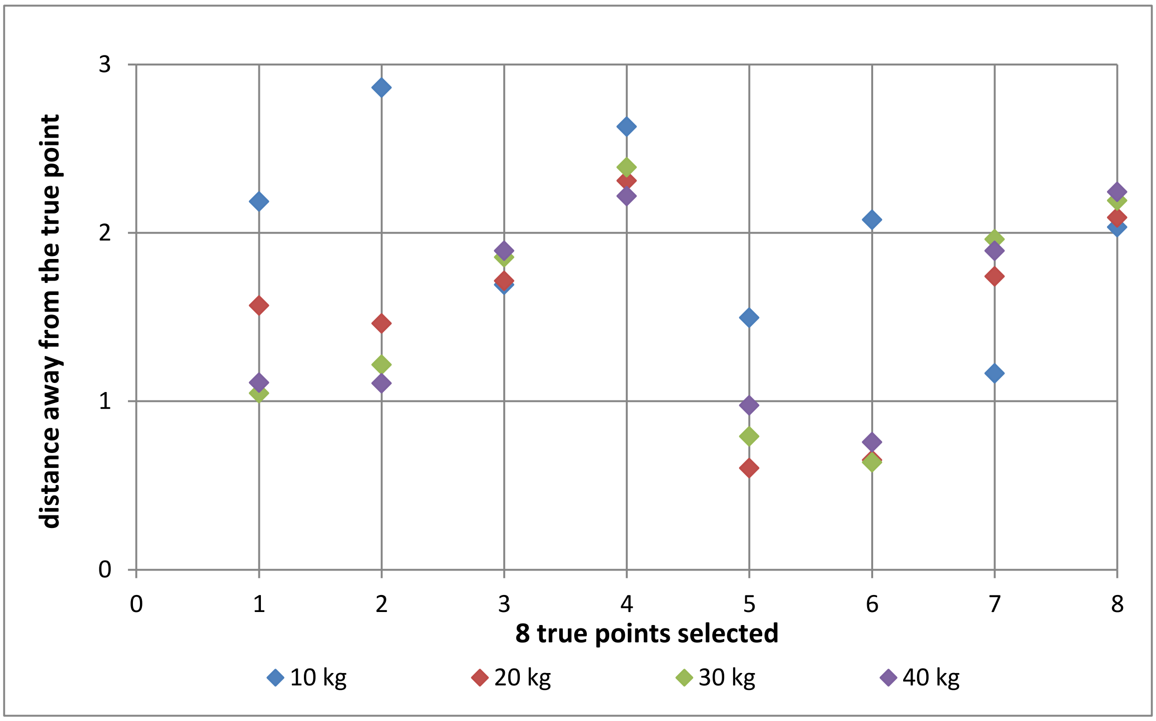


Using the Pythagoras calculation (Table 4.1 and Graph 4.3), the distance between measured points and true points ranged between 0.6 cm to 2.8 cm. These distances were not related to how heavy the weight was or how far the true point was from zero. Graph 4.4 shows that the right side is different from the left side with respect to the position of the measured points to one true point. This may be a calibration error due to the poor calibration process of Stance© where weight is applied at any location without providing any details about the location or amount of weight. No information was provided about the calibration factors included in the calculation. To correct this error, weights were applied at the [0,0] point in the following step to adjust for the differences between X and Y.

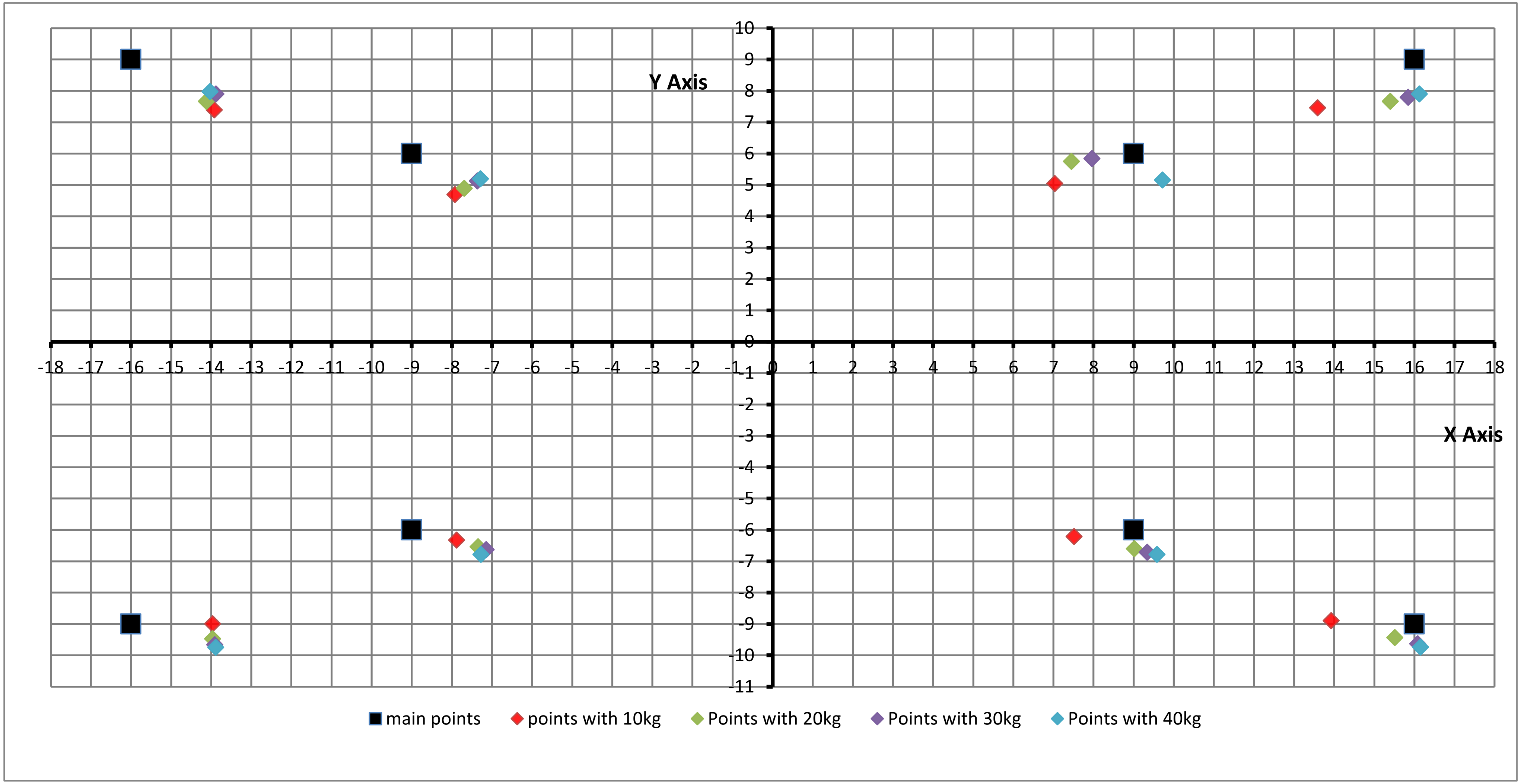
Table 4.1: Step 2 the distance between measured and true points with each weight

True points	Distance from true points with each point			
	10	20	30	40
1 [9,6]	2.19	1.57	1.05	1.11
2 [16,9]	**2.86**	1.46	1.22	1.11
3 [-9,6]	1.69	1.72	1.86	1.89
4 [-16,9]	2.63	**2.31**	**2.39**	2.22
5 [9,-6]	1.496	**0.60**	0.79	0.98
6 [16,-9]	2.08	0.65	**0.64**	**0.76**
7 [-9,-6]	**1.17**	1.74	1.96	1.89
8 [-16,-9]	2.03	2.09	2.19	**2.24**

Graph 4.3: Step 2 the distance between the true and measured points



Graph 4.4: Step 2 main points and measured points



4.4.3 Step three

4.4.3.1 Modified Procedure

Weights from 10kg to 40 kg were applied on the centre point [0,0] only.

4.4.3.2 Modified Analysis

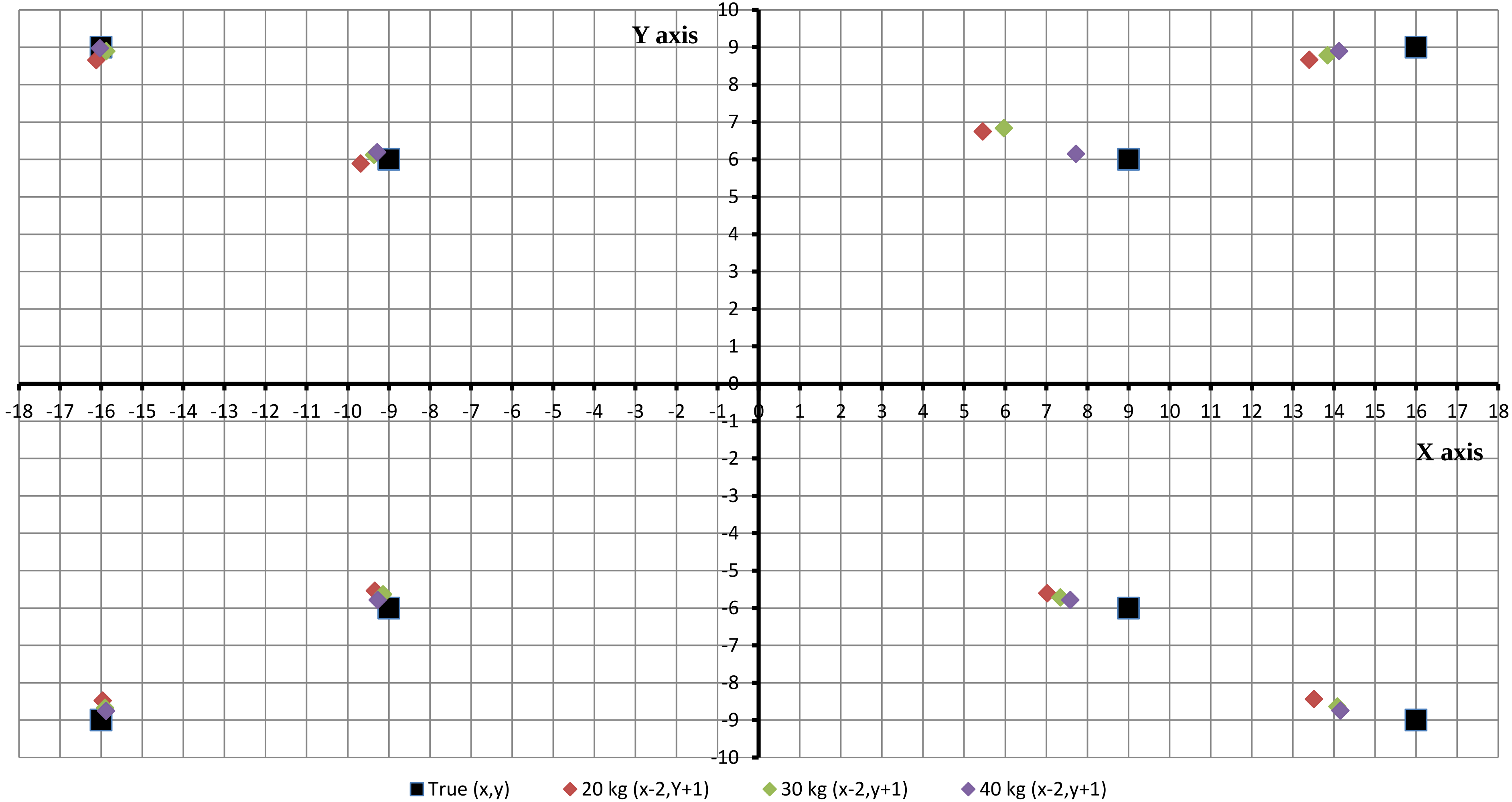
Besides the analysis mentioned in section (4.3.4), the measured point with each weight was used to re-calculate X and Y values of all measured points. This was based on the differences found in the findings of step 2.

4.4.3.3 Findings and discussion

After applying weights to point [0,0], all the weights were measured as [2, 0.5]. Graph A4.5 shows the difference between the measured X values and true X values from step two; it is evident from this graph that there is a difference of 2 cm between most measured values. Therefore, by subtracting 2 cm from all measured X values, we obtained different results, which can be seen in Graph A4.6 (Appendix 4). Graph A4.7 shows the difference between the measured Y values and true Y values from step two; it is evident from this graph that there is a difference of 1 cm between most measured values. Therefore, by adding 1 cm to all the measured Y values, we obtained different results, which can be seen in Graph A4.8 (Appendix 4).

After adjusting the X and Y values, all true points and corrected measured points were scattered on a grid graph (**Graph 4.5**). The graph shows that some measured points were the same as true points and some points were close to the true points, with minimum differences. However, there were other points that were far away from the true points. **Graph 4.5** shows that the points on the left side were closer to the true points after correction than the points on the right side. This means that it may not only be an offset error but also a scaling error of the WBB. In addition, this adjustment is not practical when calculating the COP parameters because the software, Stance©, detects the COP point and calculates the COP parameters immediately. It is difficult to adjust the values of X and Y before the COP parameters has been calculated. The results do show a possibility of instrument error in the manufacturing of the WBB. To eliminate these kinds of errors, another WBB was tested with weights and a grid sheet in Step 4.

Graph 4.5: Step 3 true and corrected measured points



4.4.4 Step four

4.4.4.1 Modified procedure

In this step, weights were applied on another WBB [WBB2] to find out if there were any consistent instrument errors.

4.4.4.2 Findings and discussion

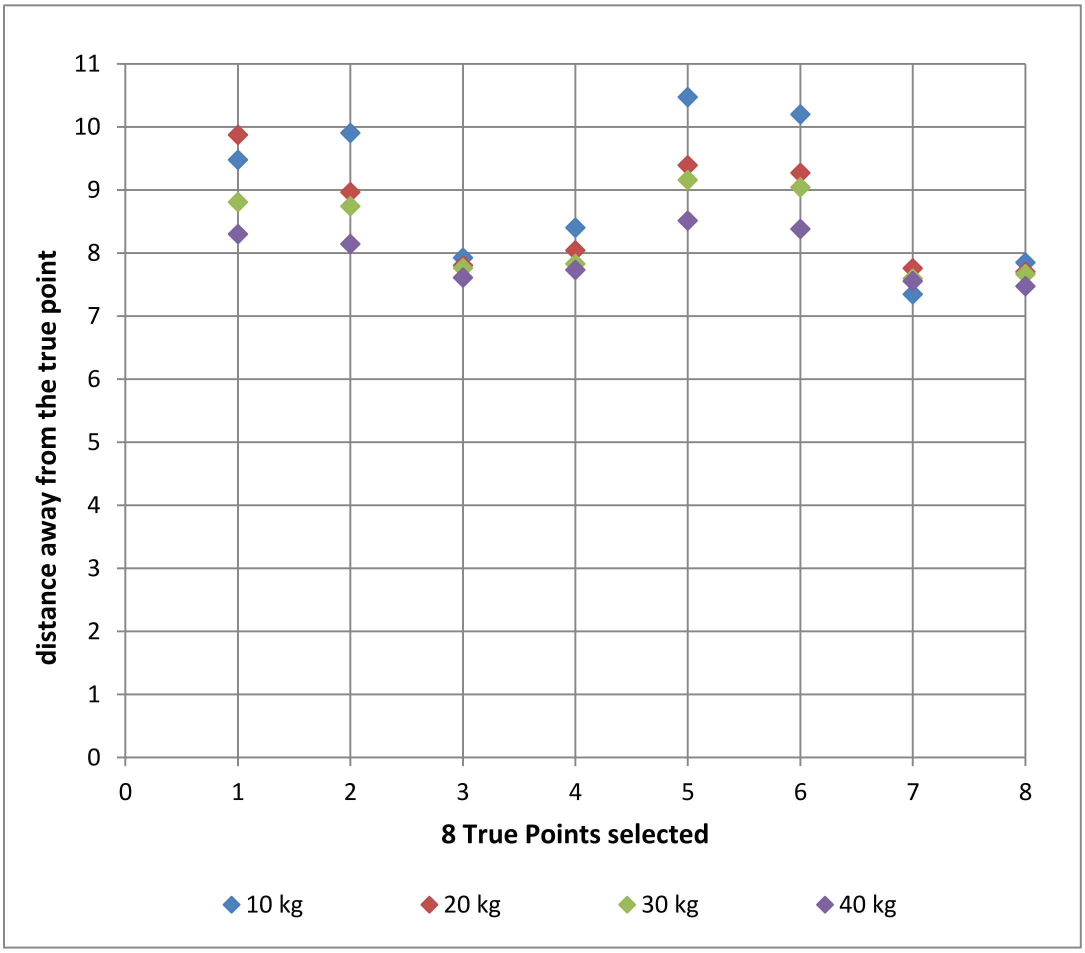
Table A4.3 shows the values of COP coordinates [x,y] separately for each point with each of the weights (Appendix 4). Graph A4.9 and Graph A4.10 shows the measured values of X and Y with each weight (Appendix 4). **Graph 4.7** shows the true and measured points on the grid sheet. It is clear from **Graph 4.7** that the values measured with WBB2 were significantly different from the true values; these values were also different from the values measured with the first WBB. Some of the measured values exceeded the actual size of the WBB, implying that they could be outliers. The distance between the measured and true points was calculated using Pythagoras theorem (**Table 4.2** and **Graph 4.6**). The distance between the measured and true points ranged between 7 cm and 10 cm, which is obviously a calibration error.

This step shows how two WBBs can yield different data output. This means that the results of extant studies that used WBB data must be interpreted with caution, especially if the study was testing the validity or reliability of WBB measurements. This step shows that a manufacturing error is not responsible for the difference in the output data of the WBBs. In fact, the major differences in the data output of the two WBBs has emphasized the importance of the calibration process. The data of the two WBBs may not be comparable or correlated unless a standard calibration formula is employed. This could be recommended as an input for future research. Although another WBB also provided measured points that were different from the true ones {approximate difference of 7–10 cm}, all the measurements were consistent, implying that even if the WBBs did not yield the same results, they provided a consistent measure. To ensure that these results are consistent, the same procedures were repeated on another day.

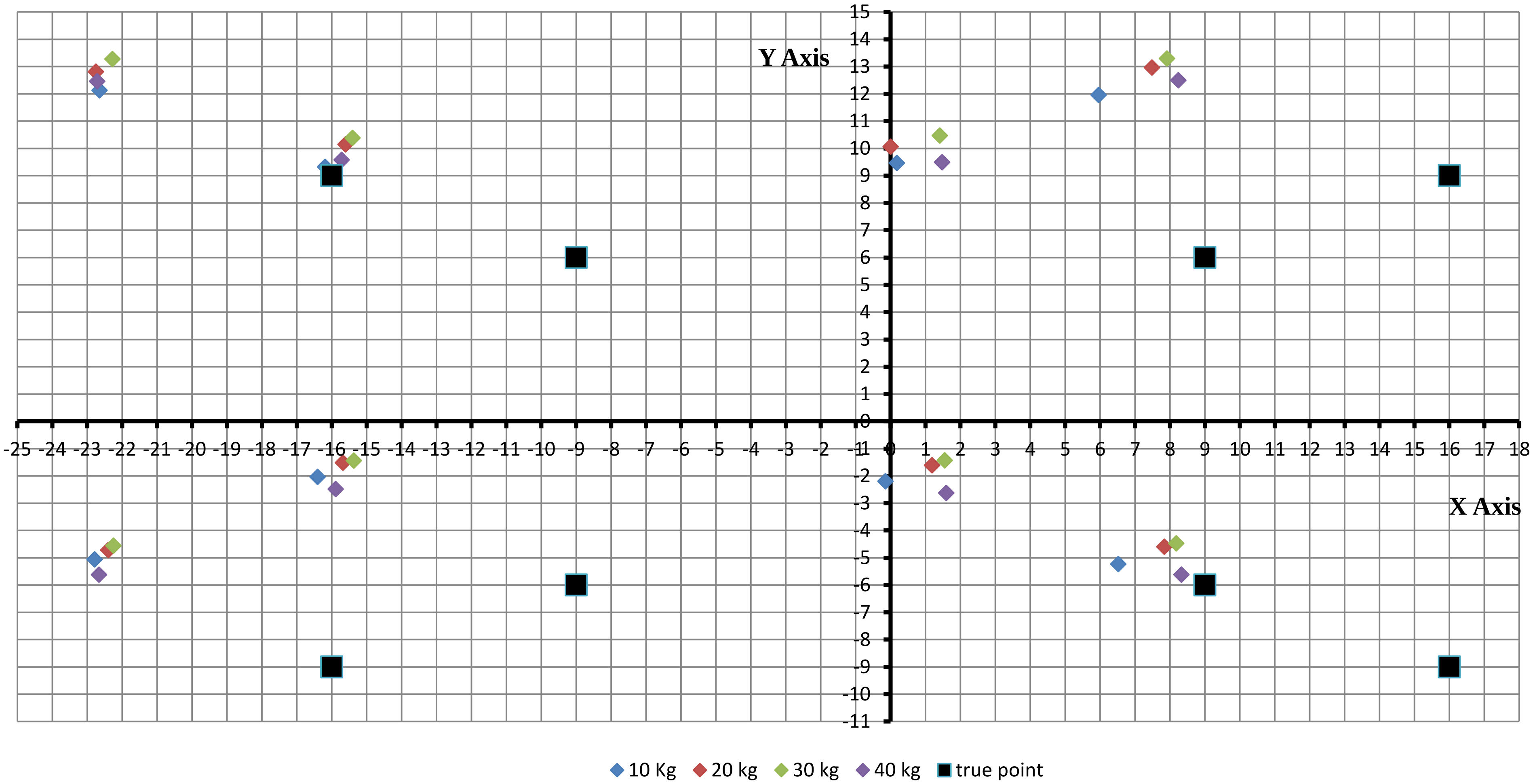
Table 4.2 : Step 4 the distance between true and measured points with each weight on another WBB2

True Points	Distance from true points with each weight			
	10	20	30	40
1 [9,6]	9.47	**9.87**	8.80	8.3
2 [9,-6]	9.90	8.96	8.74	8.14
3 [-9,6]	7.92	7.799	7.76	7.61
4 [-9,-6]	8.40	8.043	7.83	7.73
5 [16,9]	**10.47**	9.39	**9.16**	**8.51**
6 [16,-9]	10.197	9.27	9.04	8.38
7 [-16,9]	**7.35**	7.75	**7.596**	7.55
8 [-16,-9]	7.85	**7.70**	7.67	**7.47**

Graph 4.6: Step 4 the distance between the true and measured points with each weight on WBB2



Graph 4.7: Step 4 true and measured points with WBB2



4.4.5 Step five

4.4.5.1 Modified procedure

This step was the same as previous step, but performed on another day to test the consistency of the results.

4.4.5.2 Findings and discussion

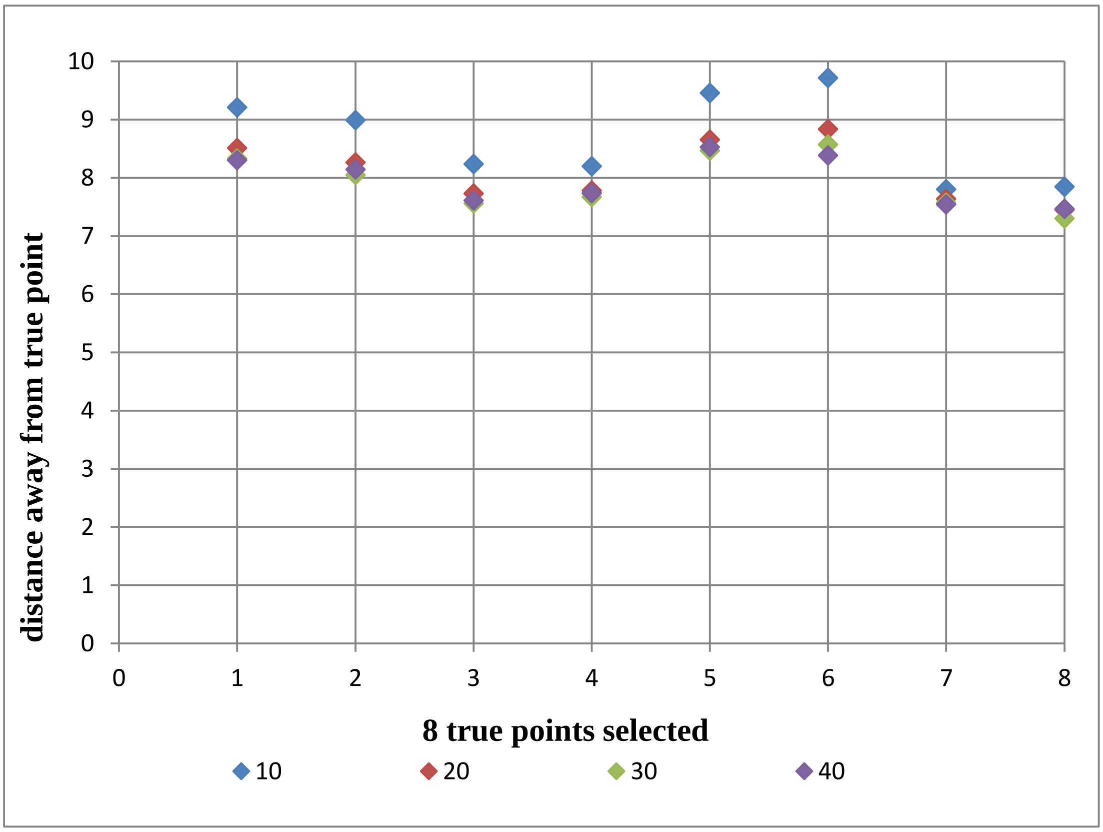
Table A4.4 shows that the measured X and Y values were not the same as the true values (Appendix 4). The measured values in this step were also slightly different from those in step 4. However, the distance between true and measured points was approximately the same as the distance found in step 4. To quantify this, the exact distance between the measured points and the true points was calculated using Pythagoras theorem (**Table 4.3** and **Graph 4.8**). The distance between the true and measured points is approximately 7 cm to 10 cm. This means that the measurements were consistent but not accurate. This consistency means that the WBB can be used to test reliability when using the same WBB. However, the results of one WBB cannot be generalized to other boards. Furthermore, this error is mainly a calibration 'offset' error.

As mentioned above, although the results are reliable and consistent, they are not accurate. This means that the COP parameters that have been obtained using Stance© also need to be tested. To test the validity of the Stance© outcome measures, they have to be tested for correlation with the outcomes of a standardized validated measure, such as a laboratory-based force plate (Haas & Burden 2000). In all the previous steps, the Stance© outcome measures were compared to static certified weights and were given a measurement error related to calibration. However, the validity of the Stance© software and WBB outcomes can be tested by investigating their correlation with the outcomes from the laboratory-based Kistler force platform. Therefore, the Stance© COP parameters were compared to the laboratory force plate COP parameters and tested for correlation in the step six.

Table 4.3: Step 5 the distance between true and measured points with each weight on WBB2 on another day

True Points	Distance from the true points with each weight			
	10	20	30	40
1 [9,6]	9.21	8.51	8.33	8.30
2 [9,-6]	8.99	8.26	8.05	8.14
3 [-9,6]	8.24	7.73	7.56	7.60
4 [-9,-6]	8.19	7.78	7.67	7.73
5 [16,9]	9.46	8.65	8.47	**8.53**
6 [16,-9]	**9.72**	**8.83**	**8.57**	8.38
7 [-16,9]	**7.799**	7.64	7.57	7.54
8 [-16,-9]	7.84	**7.45**	**7.29**	**7.46**

Graph 4.8: Step 5 the distance between true and measured points with each weight on WBB2 on another day



4.4.6 Step six

4.4.6.1 Modified Procedure

The WBB was placed on top of the Kistler force plate which was placed under the floor. A person was standing on the WBB during recording. A person was standing on the WBB when the recording was conducted. The WBB was connected to a laptop installed with Stance© through Bluetooth. The force plate was connected to a PC using a configuration software. Recordings for both Stance© and the Kistler force plate were performed simultaneously for 30 seconds.

4.4.6.2 Modified Analysis

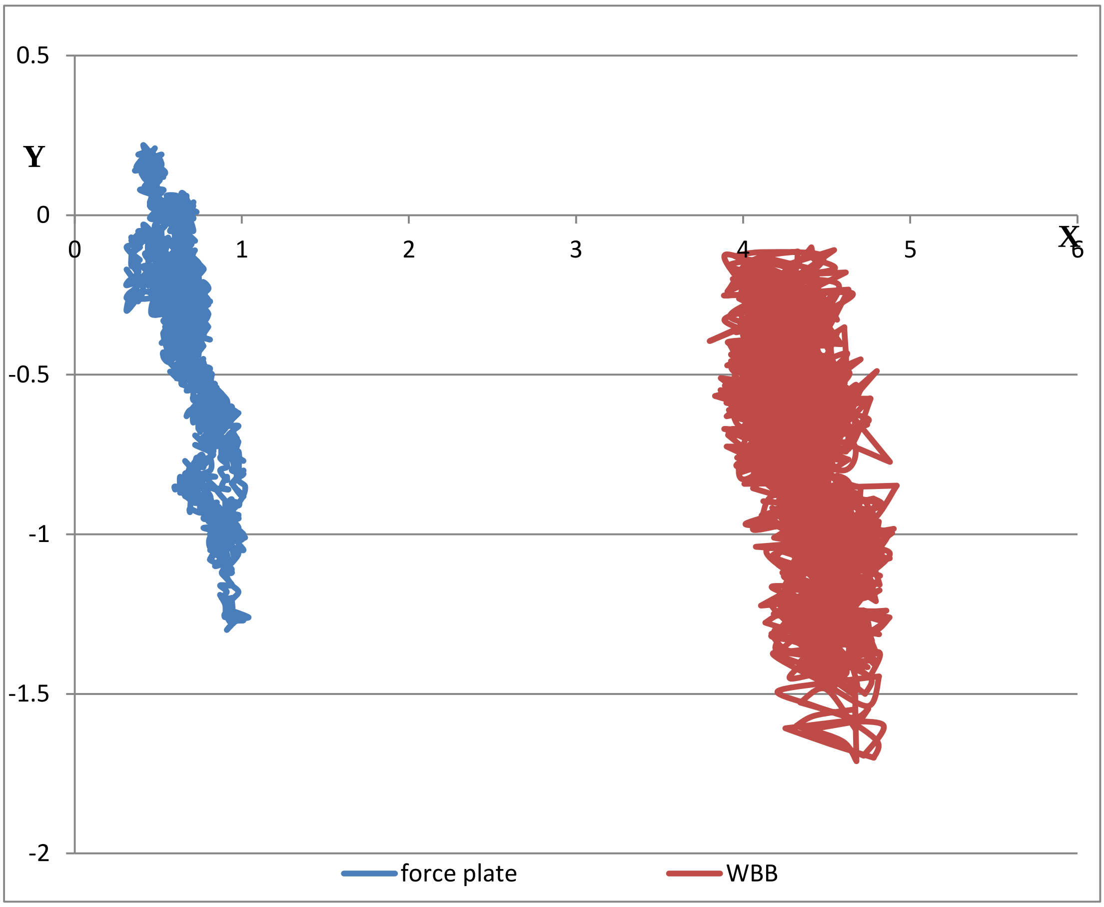
Data recorded from both the Stance© and the force plate were plotted on an Excel sheet and then scattered on a graph to show the similarities. The COP outcomes between the force plate and the Stance© were compared and the right outcomes were chosen to be tested for correlation.

4.4.6.3 Findings and discussion

The force plate reads the WBB movement and the WBB reads the standing person's movement. **Graph 4.9** shows that the WBB and the force plate returned a similar shape of data. Differences were found in the calculation of the COP sway between the Stance© and the force plate COP outcomes. The Stance© tends to locate the COP from Y and X axes and give a range of COP movement with maximum AP oscillation {Y axis}, mean and standard deviation [SD] and maximum LL oscillation {X axis}, mean and SD. This means that Stance© does not measure sway in two directions, as the force plate does; it only gives the mean of COP coordinates along the X and Y axis. Therefore, the mean COP sway measurements of Stance© cannot be compared to the force plate COP sway measurements. The COP path length was selected as the main measure to be compared.

A repetition error was detected in the time acquisition {the first column of the Stance row data}. The first 20 data samples of 0.2 seconds were copied in **Table 4.4** with all the repetition rows highlighted, and the time acquisition was scattered on **Graph 4.10**. This error has been affecting the calculation of COP length and velocity because when the data was missing the values were repeated, which gave zeros with the calculations and led to confusing, inaccurate outcomes. This type of error cannot be resampled because it could lose an amount of data that cannot be ignored. Stance software needs to be processed again to avoid this repetition error.

Graph 4.9: Step 6 recordings of a person standing on WBB which is on top of force plate



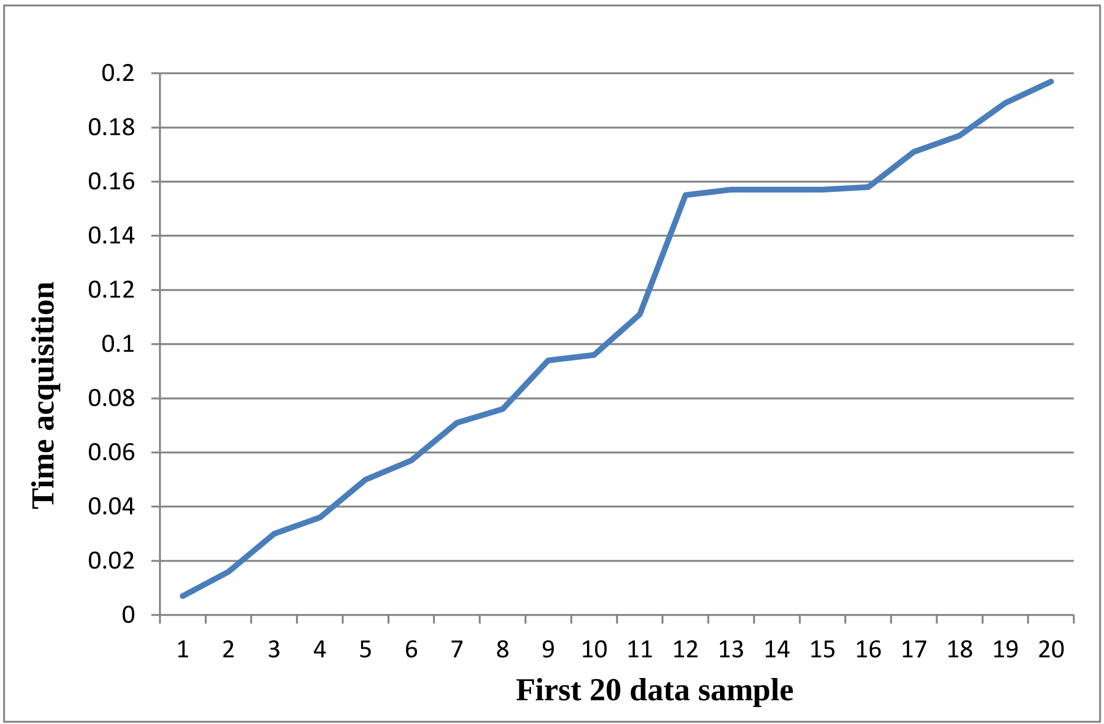
Although some researchers have used this method to analyse players' movements while playing, it does not provide accurate data because the force plate reads the WBB movement and the WBB reads the standing person's movement. Although these readings may look similar, they are not. Additionally, differences were found between Stance© and the force plate in the calculation of COP sway. This may be owing to the sensitivity of the WBB, which is not as sensitive as the force plate; however, both the WBB and the force plate calculate the COP path length in the same way. This may explain why previous research used the COP length as the main outcome measure. The results of this step revealed a repetition error in the time acquisition of data within the Stance©. This error may explain the confusing results obtained in the previous steps.

Table 4.4: Step 6 the row data from the Stance {0.2 sec} showing the repetition error highlighted

Time acquisition	X	Y	Total weight	Weight from the 4 sensors of the WBB			
0.007	4.343643	6.425481	76.40619	71.44789	83.25969	76.96956	73.94763
0.016001	4.343643	6.425481	76.40619	71.44789	83.25969	76.96956	73.94763
0.030002	4.328448	6.395304	76.44788	71.56282	83.61365	77.04623	73.5688
0.036002	4.349367	6.401281	76.40787	71.56282	83.45633	76.81624	73.7961
0.050003	4.349367	6.401281	76.40787	71.56282	83.45633	76.81624	73.7961
0.057003	4.338594	6.374262	76.52528	71.83099	83.77097	76.85457	73.64457
0.071004	4.338594	6.374262	76.52528	71.83099	83.77097	76.85457	73.64457
0.076004	4.352444	6.348506	76.53777	71.83099	84.12492	76.7779	73.41727
0.094005	4.326514	6.34554	76.44052	71.94592	83.84962	76.66291	73.30362
0.096006	4.326514	6.34554	76.44052	71.94592	83.84962	76.66291	73.30362
0.111006	4.338265	6.330158	76.3465	71.79268	84.00694	76.54791	73.03844
0.155009	4.311571	6.300365	76.52247	72.09915	84.43956	76.7779	72.77326
0.157009	4.311571	6.300365	76.52247	72.09915	84.43956	76.7779	72.77326
0.157009	4.311571	6.300365	76.52247	72.09915	84.43956	76.7779	72.77326
0.157009	4.311571	6.300365	76.52247	72.09915	84.43956	76.7779	72.77326
0.158009	4.315653	6.265272	76.34066	72.2524	84.3609	76.24126	72.50808
0.17101	4.307077	6.267129	76.4859	72.2907	84.59688	76.54791	72.50808
0.17701	4.307077	6.267129	76.4859	72.2907	84.59688	76.54791	72.50808
0.189011	4.317425	6.276115	76.46554	72.2524	84.47889	76.47125	72.65961
0.197011	4.318244	6.251808	76.40945	72.32901	84.59688	76.27959	72.43231

These previous steps were very useful because they enabled an early detection of the problem before the software was used. Even though Stance© is user-friendly, it is not valid and not ready to be used with the WBB for research. MATLAB® may be a better software to use with the WBB for measuring standing balance. MATLAB® was tested in the following step.

Graph 4.10: Step 6 the first 20 data sample of Stance and 0.2 sec time acquisition



4.4.7 Step seven

4.4.7.1 Modified Procedure

The WBB was connected to a Laptop [Windows XPS] installed with MATLAB® [R2011a] using a Bluetooth dongle (Figure 4.4) and WiimoteLib (Figure 4.3). The procedure followed in step 2 was repeated in this step.

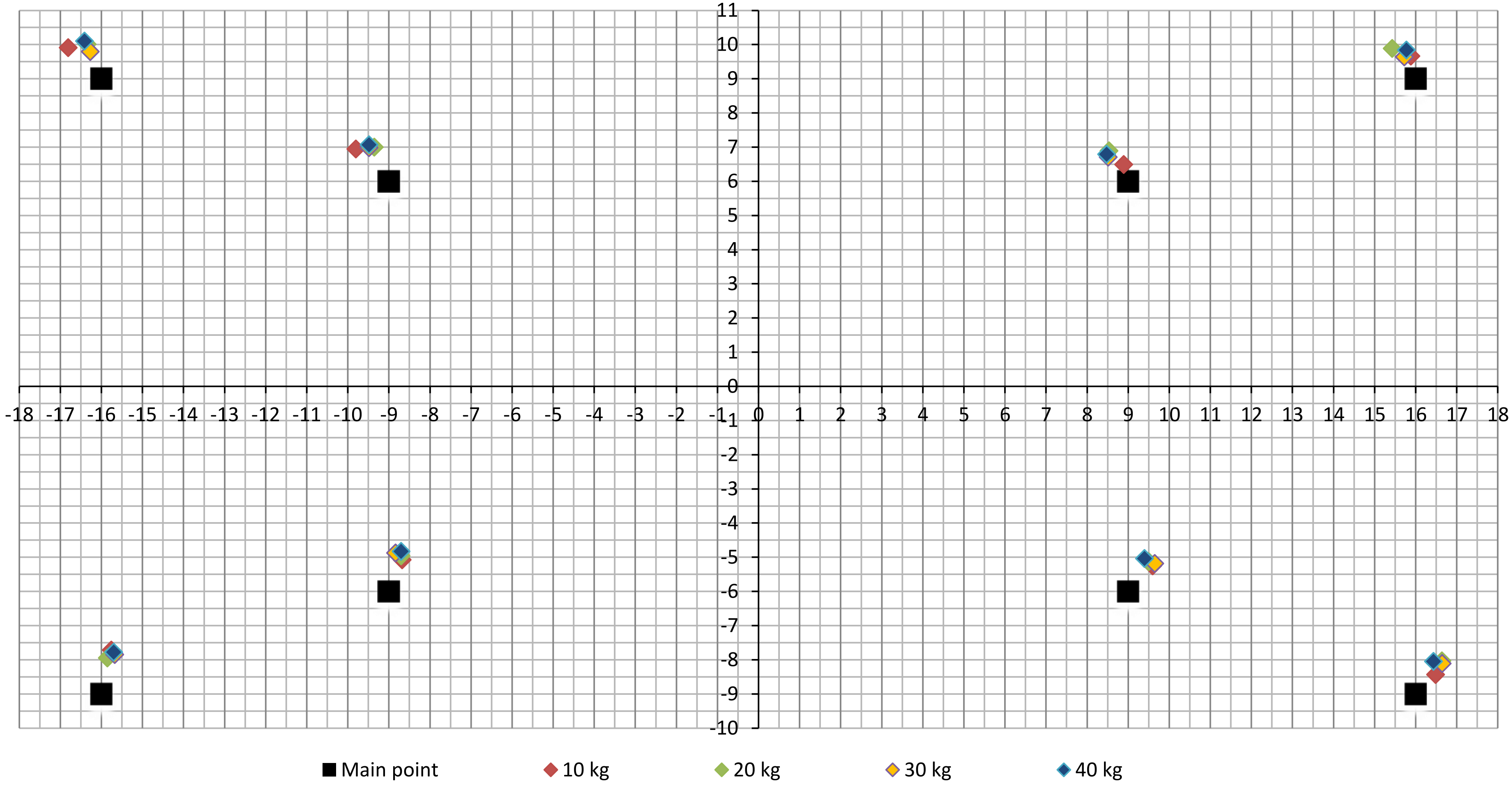
4.4.7.2 Findings and discussion

Table 4.5 shows the true and measured values of X and Y. This table shows that X values are closer to true values than Y values. All these values were plotted in **Graph 4.11** to compare the main points to the measured points. The difference between the true and measured values are lesser than that seen with Stance© in step 2. Pythagoras theorem was used to quantify the distance between the true point and the measured point (**Table 4.6** and **Graph 4.12**). In this step, the difference between the true and measured values ranged from 0.5 cm to 1.3 cm, whereas in step 2 with Stance©, the difference ranged from 0.6 cm to 2.8 cm.

Table 4.5: Step 7 true and measured values of X and Y by MATLAB®

Point	Weight + 0. 439 kg	**X**	Measured X	**Y**	Measured Y	Point	Weight + 0. 439 kg	**X**	Measured X	**Y**	Measured Y
1	10	**9**	8.8946	**6**	6.4952	5	10	**16**	15.883	**9**	9.6647
	20		8.5366		6.8911		20		15.4323		9.8866
	30		8.5151		6.7052		30		15.7228		9.6436
	40		8.4744		6.7951		40		15.7771		9.8377
2	10	**9**	9.5972	**-6**	-5.2487	6	10	**16**	16.4855	**-9**	-8.4295
	20		9.5008		-5.1285		20		16.6401		-8.0345
	30		9.6469		-5.1808		30		16.6478		-8.1099
	40		9.3978		-5.0340		40		16.4375		-8.0472
3	10	**-9**	-9.8002	**6**	6.9445	7	10	**-16**	-16.8043	**9**	9.91196
	20		-9.3533		6.9999		20		-16.3479		10.0120
	30		-9.4838		6.9829		30		-16.2701		9.7966
	40		-9.4801		7.0693		40		-16.4073		10.1029
4	10	**-9**	-8.6730	**-6**	-5.0740	8	10	**-16**	-15.7593	**-9**	-7.7138
	20		-8.7027		-4.9601		20		-15.8516		-7.9439
	30		-8.8336		-4.8769		30		-15.6765		-7.8431
	40		-8.7044		-4.8260		40		-15.6998		-7.7740

Graph 4.11: Step 7 main and measured points by MATLA

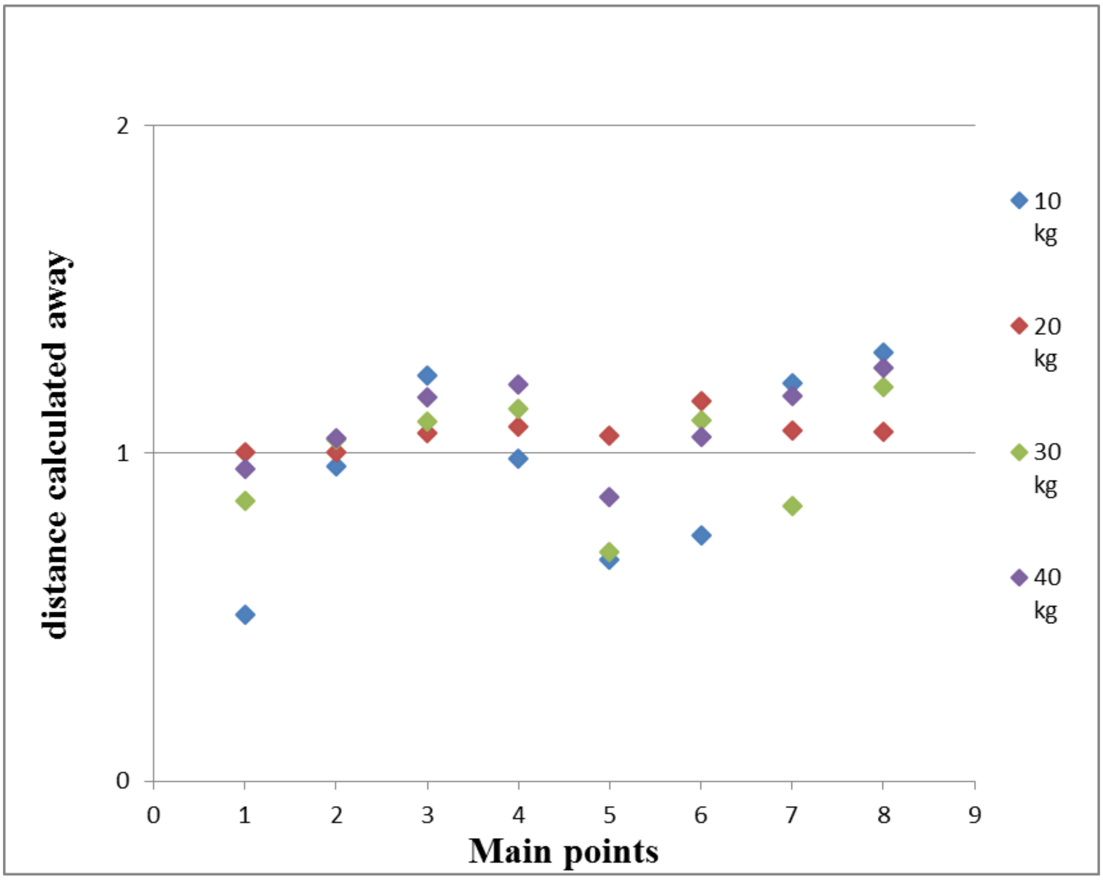


When comparing Graph 4.11 with Graph 4.4, all the measured points were found to be the same, with a weight applied on each true point. This means that the MATLAB® measurements were consistent, with a distance difference of approximately 1 cm. In addition, Graph 4.11 shows that with MATLAB®, there was no difference between the right and left sides, whereas in Graph 4.4, with Stance©, there were obvious differences between the two sides. This may be because the calibration process of MATLAB® was more rigorous than the calibration process of Stance©. Neither MATLAB® nor Stance© yielded measured points that were equal to the true points; however, MATLAB® provided more consistent results with fewer differences. The difference may be a set error of the WBB that is instrumental in manufacturing, which may not be corrected with calibration. However, the calculation of the COP length is unlikely to be affected by this difference because the length is calculated by the distance and not by the X and Y values. Therefore, the software program MATLAB® (Appendix 3) will be used as the communicating software with WBB for balance assessment and the COP path length will be used as the outcome measure.

Table 4.6: Step 7 the distance between true and measured points by MATLAB®

Main point		**Distance between main point and measured point with each weight**			
		10	**20**	**30**	**40**
1	[9,6]	**0.51**	**1.00**	0.86	0.95
2	[9,-6]	0.96	1.00	1.04	1.04
3	[-9,6]	1.24	1.06	1.095	1.17
4	[-9,-6]	0.98	1.08	1.14	1.21
5	[16,9]	0.67	1.05	**0.70**	**0.87**
6	[16,-9]	0.75	**1.16**	1.10	1.05
7	[-16,9]	1.22	1.07	0.84	1.16
8	[-16,-9]	**1.31**	1.07	**1.20**	**1.26**

Graph 4.12: Step 7 the difference between main and measured points by MATLAB®



4.5 General discussion of the developmental work

Since the WBB can communicate with the Wii console through Bluetooth, it can also communicate with other hardware devices. Researchers have shown keen interest in the high technology of this game tool to either design games for a specific population or using it as an assessment tool in rehabilitation. However, because the WBB was originally designed as a tool to play Wii games and not for research or clinical purposes, researchers could not comprehend how its data could be used for research purposes. Designing a software program that can communicate with the WBB, capture its data and calculate a quantitative outcome measure is a challenging task. However, Clark et al. (2010) were the first who conducted some experiments on the WBB to calibrate it and test its concurrent validity with the force plate. The calibration process and calculation equations of COP length, which was published by Clark et al. (2010), has been followed by other researchers owing to a lack of clarification and understanding of the functioning of the WBB. Although this calibration process has been programmed using LabVIEW software, it can be used with other software programs. Since the research team was unfamiliar with LabVIEW, Stance© and MATLAB® software programs were selected. The validity of both the software outcomes was tested before being selected for use with the WBB in standing balance assessments.

Results from the steps of this developmental work have generated useful insights, which were not found in the literature. For example, the first step revealed that the minimum weight that the WBB can measure is 10 kg. This is an important consideration when assessing children. Furthermore, steps four and five revealed that the measurements of two WBBs will be different unless they are calibrated in the same way. Therefore, the results of the studies that have used WBB data must be interpreted with caution. Further research needs to be conducted to test the reliability across different WBBs to formulate a standard calibration process.

Using a fixed calibration process, MATLAB® yielded data outcomes where the true and the measured points were slightly different; however, the differences between the points were smaller than those seen with Stance© and the results were more consistent. These differences may be a set error of the WBB that is instrumental in manufacturing and cannot be corrected with calibration. Communication disruption between the WBB and the laptop may be another reason for these differences. However, the calculation of COP length is unlikely to be affected by this difference because the length is calculated by the distance and not by the X and Y values.

The advantages of using the WBB is summed up by its portability and cost effectiveness, which makes it a useful assessment tool in clinical settings to close the gap between functional balance assessments and laboratory force plates. However, communicating with the WBB is a major obstacle, especially for clinicians. A user-friendly software like Stance© needs to be made available for clinician use, with a better programmed algorithm like that of other math software programs, such as LabVIEW or MATLAB®. The results of the six steps show that Stance© is not ready to be used with WBB, even though it follows the protocol of Clark et al. (2010). It has shown a calibration error and a data acquisition error, which leads to inaccurate calculations of COP parameters. Recently, with the development in the WBB literature, Park & Lee (2014) introduced a new user-friendly software called Balancia that can be used with the WBB. This software with the WBB showed high concurrent validity and good reliability results suggesting it to be used in clinical practice. However, this study results were not available while this developmental work was conducted.

The main limitation of this work is that MATLAB® was only tested once, whereas Stance© was tested six times. This is because Stance© outcomes were confusing and unacceptable, which led to further testing until the true error was found. As mentioned above, although the measurement points yielded by MATLAB® are different from true points, the differences were acceptable and consistent. Instead of using stable weights, MATLAB® needs to be tested with individuals standing on the WBB and the COP length should be calculated to ensure that this measure remains unaffected by the differences in COP coordinates (Chapter 5).

4.6 Conclusion

This developmental work has highlighted the potential problems in using raw data from a commercially available game tool, the WBB, for research. One main problem was finding a software program that would effectively communicate with the WBB. Testing the validity of software outcomes was very useful in detecting possible errors before using the software. It was found that some problems could be resolved with proper connection and calibration of the WBB. Every step of the developmental work revealed more information, including the minimum weight limit that the WBB can measure is 10 kg, difference between the two WBBs, consistency in the WBB's readings, difference between the Kistler force plate and the WBB in measuring COP sway, and importance of data acquisition in calculating COP parameters. This chapter provided an overview of the practicality of using the WBB in clinical and research settings and the potential errors that could be found with the software communicating with the WBB. The next chapter contains a reliability study of the WBB with children using the MATLAB® software program.

Chapter 5: Intra-session and Inter-session reliability of the WBB when assessing standing balance in children

5.1 Introduction

As the WBB was a new tool in the market, up until the year 2012, only few studies investigated its applicability for balance assessment (Clark et al. 2010; Clark et al. 2011). However, within the last three years, more researchers have investigated the reliability and validity of WBB outcomes to assess standing balance (Chang et al. 2013; Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Holmes et al. 2013b; Bower et al. 2014; Larsen et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Sgrò et al. 2014; Abujaber et al. 2015; Jeter et al. 2015; Pavan et al. 2015). As discussed earlier in Chapter 3 (section 3.3.1), All studies agreed that the WBB's data of COP are valid and comparable to data from laboratory force plates, and showed excellent test re-test reliability. However, these studies were conducted with adult population not children. Whereas very limited studies have been conducted among TD children. This gap in literature needs to be filled because once a reliable measure of standing balance is established using the WBB with TD children, reference data for TD children can be obtained. Subsequently, the WBB can be used to examine children with balance impairments, such as children with CP. Therefore, this chapter will include a study that will aim to test the reliability of the WBB assessment of standing balance in TD children.

Ruhe et al. (2010) conducted a systematic review of literature concerning the reliability of COP parameters measured by different force plates. This study made some recommendations for maximising the reliability of COP parameters when measuring static standing balance. These recommendations included the most reliable parameters, number of repetitions and duration of testing. Ruhe et al. (2010) concluded that a minimum testing duration of 90 seconds with 3 repetitions is required to achieve an acceptable reliability. This result was based on testing bilateral standing among an adult population. However, this testing duration may not be practical for children because their postural stability is still maturing. This means that these recommendations may not be applicable when investigating standing balance ability in children.

The standing balance of children, both healthy and disabled, has been tested in the literature. The majority of studies have tested bilateral standing and only a few studies considered unilateral standing. Moreover, only a few studies have explored the reliability of COP parameters among children. Thus far, it is not clear which testing duration is most reliable for use with children. Rival et al. (2005) tested the reliability of COP parameters of unilateral standing in school-age children. Theses researchers have concluded that children between the ages of six and ten years were able to stand on one leg and maintain a postural stability for ten seconds. To the best of our knowledge, no further research has been conducted to investigate whether children can maintain balance on one leg for more than ten seconds.

Additionally, the studies which showed the reliability and validity of WBB's data were based on a testing duration of 30 seconds with bilateral standing and ten seconds with unilateral standing. However, thus far, a longer duration, such as 60 seconds, has not been tested for reliability with the WBB. In general, standing for 60 seconds on both legs and for 30 seconds on one leg may not be feasible for children. Therefore, a pilot study will be conducted to determine the feasibility of testing children for longer durations. Following the pilot's results, a few modifications to the testing procedure were applied to the reliability study.

5.2 Aim

The aim of the study was to test the intra-session and inter-session reliability of the WBB when assessing COP path length in school-age TD children.

5.3 Methodology

5.3.1 Sample & recruitment

Atkinson & Nevill (2001) recommended a sample size between 15 and 20 participants for a reliability study. Therefore, 17 children were recruited for the study. The first four children were involved only in the pilot study and the other 13 children participated in the reliability study.

Children who attended a primary school in Southampton were sent an invitation letter to participate in the study; these letters were distributed to them by their schoolteachers. Saudi families who lived in Southampton and whose children studied in Southampton were also sent invitation emails by the Saudi Students' Club. Invitation letters and emails included parents' information sheet (Appendix 5), children information sheet (Appendix 6) and the contact details of the researcher.

5.3.1.1 Inclusion /exclusion criteria

Inclusion criteria: Children between the ages of 6 to 12 years old

Exclusion criteria: Those children whose parents reported that they were suffering from any of the following medical conditions were excluded from the study:

1. Musculoskeletal pathology or pain that would influence balance
2. Neurological impairments, such as CP
3. Blind or visual impairments that cannot be corrected by prescribed glasses or lenses

Children were also excluded from the study if their parents reported any of following events:

4. Recent injuries that would prevent them from standing for 10 minutes or more
5. Any involvement in balance training exercises

5.3.1.2 Consents

Before the testing session was initiated, parents were asked to sign the parents' consent form (Appendix 7) and children were asked to complete the children's assent form (Appendix 8) with the help of researcher, if required. The parents were subsequently asked to complete the child screening sheet (Appendix 9), which provided each child with an ID code so that he/she could be identified by the researcher. Ethical approval was obtained from the ethics committee of the Faculty of Health Sciences at University of Southampton (Appendix 10).

5.3.2 Settings

5.3.2.1 Equipment setting

The WBB was connected to a laptop through a Bluetooth dongle. Data from the WBB was recorded and saved using MATLAB® software. The manner in which the WBB and MATLAB® are connected and the calculation of COP length has already been described in Chapter 4. The WBB was calibrated in two steps at the beginning of the session before testing: 1) calibration with no weight applied to the WBB and 2) calibration with a certified 5 kg weight placed at the centre of the WBB.

5.3.2.2 Lab setting

The study was performed in a gait lab at Southampton General Hospital. The lab is equipped with a bathroom scale and a one-meter ruler attached to the wall at a height of one meter from the floor. These were used to record the weight and height measurements of each child. The WBB was placed on the floor, in the middle of the lab, and surrounded by mat sheets. Subsequently, the WBB was covered with a rubber cover to prevent children from slipping and this cover had foot marks to standardise the feet position of the children. A chair was placed one meter behind the WBB and the mats for children to sit on and rest. An image poster was placed on the wall in front of the WBB for the children to look at during the eyes-open trials.

5.3.2.3 Safety

To ensure the children's safety, the researcher closely monitored their movements to check for signs of potential falls and stopped the test for rest periods whenever necessary. The researcher stood behind the children during the eyes-open trials and in front of the children during the eyes-closed trials. Furthermore, the lab experimental officer, who recorded the testing trials, was a first aid officer, who was equipped to take immediate action in the event of a fall.

5.4 Pilot study

5.4.1 Aim

The aim of the pilot study was to determine a feasible testing duration by assessing whether children can maintain standing balance on both legs for 60 seconds and on one leg for 30 seconds.

5.4.2 Methods

5.4.2.1 Sample

The first four children who participated in the reliability study were recruited for this pilot study.

5.4.2.2 Procedures

Children only attended one session. They were asked to remove their shoes for height and weight measurements. The children were asked to stand on the WBB and perform four tasks, repeating each task thrice. The children were given the option to rest on a chair between repetitions and tasks until they were ready for the next task. The tasks were as follows:

1. Stand on both legs with eyes open [EO2L] for 60 seconds.
2. Stand on both legs with eyes closed [EC2L] for 60 seconds.

3. Stand on one leg with eyes open [EO1L] for 30 seconds.
4. Stand on one leg with eyes closed [EC1L] for 30 seconds.

The children were not given any further instructions, and they were observed during testing. Any comments or feedbacks from the children were recorded.

5.4.3 Data analysis

The feedback from the children and the observations of their behaviour with long duration testing were the main sources of data for this pilot study. In addition, each child had twelve recordings, which comprised four tasks, each of which was repeated thrice. The recorded row data from MATLAB® included six columns of data: the weights on each of the four sensors and the X and Y coordinates of COP. These data files were copied to an Excel worksheet for the calculation of total COP path length. The total COP path length, which was calculated using Pythagoras theorem, provides the distance between each COP point and the previous point and the sum of these distances provides the total length of COP movement.

5.4.4 Results

Four children, three males and one female, with a mean age of 8.75 ± 1.7 were included in this pilot study (Table 5.1). The COP length was not calculated for the pilot study because children were unable to stand for 30 sec on one leg. Furthermore, some errors were found in the raw data, which needed to be corrected to obtain the correct COP length. Other observations are discussed in the following section.

Table 5.1: Demographic characteristics of children in the pilot study

ID	Gender	Age	Height [cm]	Weight [kg]	BMI
01	M	11	139	31	16
02	M	9	128	22	13.5
03	F	7	117	22	16.2
04	M	8	137	35	18.6
Mean	**-**	**8.75**	**130.25**	**27.5**	**16.075**
SD	**-**	**1.71**	**10.05**	**6.56**	**2.08**

5.4.5 Discussion of pilot

5.4.5.1 Observations

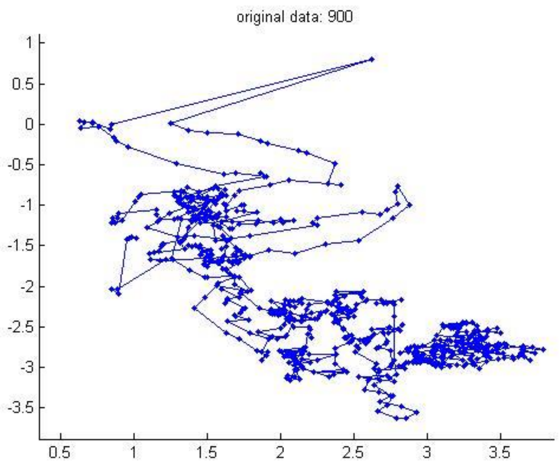
In the first two tasks, which required children to stand on both legs with eyes open or eyes closed, the testing duration was 60 seconds. Children reported that the duration of the test was long and boring. Some children stated that they felt dizzy and tired, especially in the eyes-closed trials. Children were asked to stand as still as possible but were given no further instructions while they were standing. It was observed that different children behave differently while standing. For example, some children placed their hands behind their back, some put their hands in their pockets and others scratched their nose or head. These movements are likely to affect their COP data.

The children found the third and fourth tasks, which required them to stand on one leg with their eyes open or closed for 30 seconds, very challenging. The children were asked to stand on their dominant leg, which is identified by which leg that they would use to kick a ball. Some children could not balance on their dominant leg and chose to stand on the non-dominant leg. This implies that the dominant leg may not be the more stable leg because children use the non-dominant leg to support themselves while kicking a ball. Most of the children put down the raised leg and then lifted it up again during the recording. It was noticed that most children could balance for 10 seconds; however, they subsequently lost their balance and became susceptible to falling. Although the researcher stood next to children, the children avoided leaning on her; in fact, they leaned in the opposite direction, which increased their balance disturbance and their risk of falling. The children's inability to maintain balance on one leg encouraged them to continue trying. They were excited about repeating the task and proving that they could do it, especially when they had failed to do it the first time.

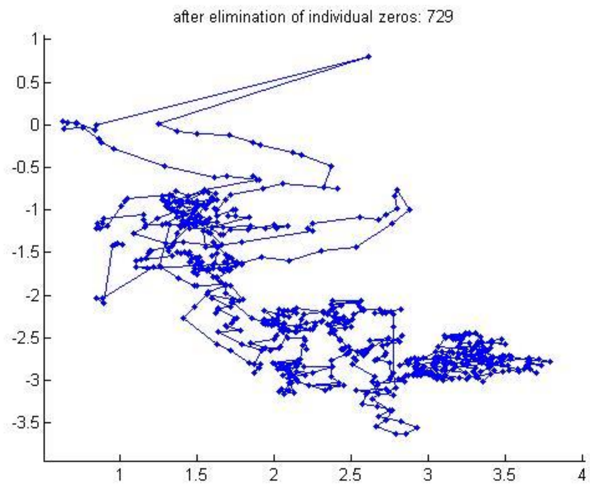
5.4.5.2 COP path length

As MATLAB® was capturing data from the WBB through Bluetooth, other Bluetooth devices affected the data stream and caused repetitions in time acquisition. This has resulted in data transmission glitches, which is missing data points by drop-outs and spurious outliers, which is single data points that are far away from the COP path, in the recordings. This error may have occurred because of a slow or disrupted connection between the WBB and MATLAB® or slow processing power of the computer. It led to some recordings with small number of data points, reducing the quality of the total COP path length calculation. To compensate for this error, data was pre-processed with a MATLAB® algorithm (Appendix 11) to remove spurious outliers or repeated data points. Figure 5.1 illustrates an example of how COP data points were processed.

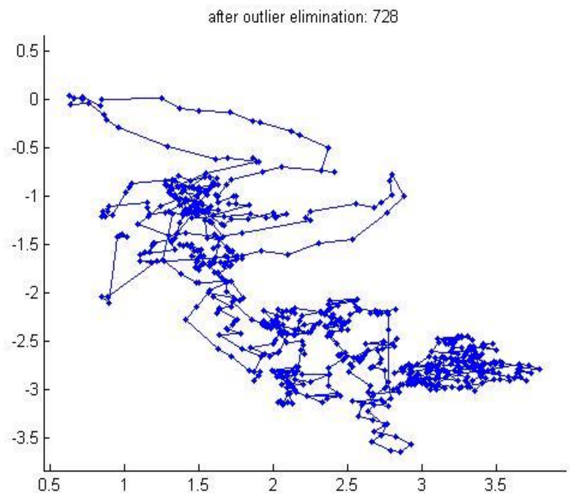
This provided an outcome of COP path length per time unit [cm/sec], which was calculated according to the time unit ‘seconds’ based on the average COP path length with the average time recorded.



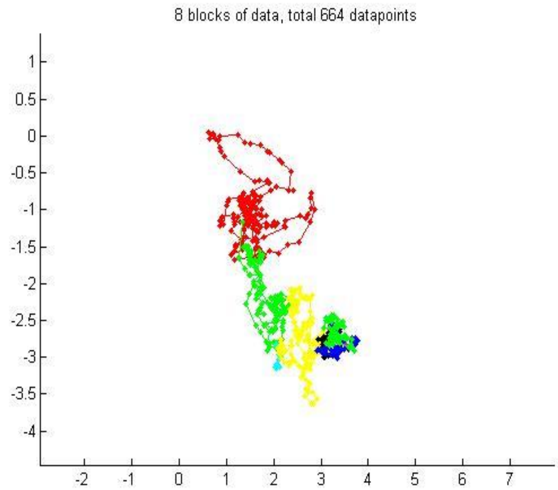
A) The original COP data



B) After removal of repeated data points



C) After removal of outliers



D) The final COP length

Figure 5.1: Example of the COP length after the removal of spurious outliers and repeated data points

5.5 Summary of decisions after pilot

In light of the previous observations, the following decisions were made:

1- The testing duration for the reliability study will be limited to 30 sec for trials standing on both legs and 10 sec for trials standing on one leg to avoid children from falling, feeling dizzy or getting bored.

2- Children will be instructed to stand as still as possible and to avoid moving their heads or arms during testing. Any recording that includes unwanted movement of the head or upper limb will be deleted and repeated.

3- Children will be instructed to sit on the chair and count to 20 between repetitions and tasks to ensure that all children get a consistent amount of rest.

4- In tasks that require children to stand on one leg, they will be permitted to choose the leg that they would like to stand on, and any recording that includes putting the raised foot down will be deleted and repeated.

5- The researcher will stand behind the child during the eyes-open tasks and in front of the child during the eyes-closed tasks. This will ensure safety and permit the child to move his/her arms freely to maintain balance.

6- After recording, the data will be processed with a MATLAB® algorithm (Appendix 11) to remove any outliers or repeated data points for calculating the COP path length per time unit ‘cm/sec’.

5.6 Modified methodology

Once the pilot study was complete, a few modifications were applied to the testing procedures and data analysis

5.6.1 Testing procedures

Children attended two sessions in one week. The duration of each session was 20–30 minutes. Children were asked to remove their shoes and step onto a weighing scale so that their weight and height could be recorded. Subsequently, they were asked to step on the WBB to perform four tasks. Each task was repeated thrice with a rest period of 30 seconds between each repetition:

1- Stand on both legs with eyes open [EO2L] for 30 seconds

2- Stand on both legs with eyes closed [EC2L] for 30 seconds

3- Stand on one leg with eyes open [EO1L] for 10 seconds

4- Stand on one leg with eyes closed [EC1L] for 10 seconds

Children were instructed to stand as still as possible, without moving their arms while testing during tasks 1 and 2. They were asked to stand on their preferred leg during tasks 3 and 4 and to choose the same leg when repeating the tasks. In task 4, when the child opened his/her eyes or put the raised foot down, the recording was deleted and the task was repeated up to five times to achieve three complete recordings. Some children found it difficult to perform task 4. Furthermore, recommendations from the pilot study were applied (please refer to Section 5.5).

5.6.2 Data analysis

All the recorded data was processed using a MATLAB® algorithm (Appendix 11) to remove any outliers, zeros or repeated data points. Subsequently, the COP path length per time unit 'cm/sec' was calculated. This was the main outcome measure, which was tested for reliability.

Data was downloaded into Excel and analysed using IBM SPSS 20. The Shapiro-Wilk test was used to test the normal distribution of the data. Descriptive statistics were used to describe the mean and SD of the data. Repeated measures of Analysis of Variance [ANOVA] F-test were used to test the significant variability between the three repetitions of each task in each session. The one-way ANOVA was used to test the intra- and inter-session reliability. The [ICC $_{1,1}$] with 95% confidence interval [CI] and the standard errors of measurements were used to test intra-session reliability {within each session}. The standard errors of measurements [SEM] was calculated using the following equation (Portney & Watkins 2000):

$$SEM = SD \times (\sqrt{1 - ICC})$$

To test inter-session reliability {between sessions}, the ICC $_{1,3}$ with 95% CI, SME, and the MDC were used. The MDC was calculated using the following equation (Beckerman et al. 2001; de Vet et al. 2006):

$$MDC = 1.96 \times \sqrt{2} \text{ X } SEM$$

To interpret reliability from ICCs, the following scale, which has been proposed by Portney and Watkins (2000), was followed: <0.50: poor; 0.5–0.75: moderate; >0.75: good reliability and >0.90: excellent reliability and clinically accepted.

5.7 Results

The study was conducted from October to December 2012. Twelve children completed the study; one child withdrew from the study. The participant group comprised six boys and six girls, with a mean age of 8.5 ± 1.9 years. Their other demographic characteristics are presented in **Table 5.2**.

Table 5.2: Demographic characteristics of children in the reliability study

ID	**Age**	**Gender**	**Weight [kg]**	**Height [cm]**	**BMI**
1	6	F	22	118	15.8
2	9	M	36	138	18.9
3	12	M	70	153.5	29.9
4	7	F	23	119	16.2
5	8	F	18	118	12.9
6	8	F	22	123	14.5
7	6	M	20	118	14.4
8	8	F	22	119	15.5
9	11	M	35	148	16
10	11	M	31	149	14
11	8	M	26	126	16.4
12	8	F	18	108	15.4
Mean	**8.5**	**-**	**28.5**	**128.1**	**16.7**
SD	**1.9**	**-**	**14.4**	**15**	**4.4**

Each child completed two testing sessions. Each session included 12 recordings {4 tasks repeated thrice each}. Each recording was initially saved in a notepad data file and subsequently downloaded to a MATLAB® algorithm, which calculated the COP length [cm/sec] for each recording. Three COP length recordings for each child were grouped for each task (Appendix 12). Following the Shapiro-Wilk test, the data for each task was found to be normally distributed. Moreover, the repeated measures of the ANOVA [F-test] showed no significant variability among the three COP length recordings, except for the data in task 4 [EC1L] from session two.

5.7.1 Intra-session reliability

Data from the first and second sessions were tested for intra-session reliability separately (**Table 5.3** and **Table 5.4**). Some children could not perform task 4 [EC1L for 10 sec] in either session, some could perform only one or two repetitions and others could not perform it in the first session, but succeeded in the second session.

The results of both the sessions indicate that task 1 [EO2L] provided excellent reliability [session 1: ICC = 0.915; session 2: ICC = 0.953] with a range of 95% CI [session 1: CI = 0.79–0.97; session 2: CI = 0.88–0.98] and a SEM of 0.2. The mean COP length for all children was 2.7 cm/sec. Task 2 [EC2L] also provided excellent reliability and the results for this task were similar to that of task 1 (**Table 5.3** and **Table 5.4**). This implies that standing on both legs for 30 sec with eyes open or closed provides a reliable measure of COP length per sec.

Table 5.3: Intra-session reliability of session one

Task		Trials [n]	Mean	SD	ICC 1,1	lower CI	upper CI	SEM
1	EO2L	3 [12]	2.79	0.72	0.915	0.799	0.972	0.21
2	EC2L	3 [12]	2.89	0.82	0.889	0.744	0.963	0.27
3	EO1L	3 [10]	6.67	1.98	0.770	0.491	0.929	0.95
4	EC1L	2 [7]	9.23	2.61	0.866	0.462	0.975	0.96

EO2L= standing on both legs with eyes open, EC2L= standing on both legs with eyes closed, EO1L= standing on one leg with eyes open, EC1L= standing on one leg with eyes closed, SD= Standard deviation, ICC= interclass correlation coefficient, CI= confidence interval, SEM= standard errors of measurements

Table 5.4: Intra-session reliability for session two

Task		Trials [n]	Mean	SD	ICC 1,1	lower CI	upper CI	SEM
1	EO2L	3 [12]	2.73	0.78	0.953	0.884	0.985	0.169
2	EC2L	3 [12]	2.96	0.75	0.918	0.805	0.973	0.215
3	EO1L	3 [12]	6.91	2.3	0.708	0.423	0.894	1.243
4	EC1L	2 [10]	10.39	2.87	0.426	-0.207	0.815	2.174

EO2L= standing on both legs with eyes open, EC2L= standing on both legs with eyes closed, EO1L= standing on one leg with eyes open, EC1L= standing on one leg with eyes closed, SD= Standard deviation, ICC= interclass correlation coefficient, CI= confidence interval, SEM= standard errors of measurements

The mean COP length for task 3 [EO1L] was longer [6.6–6.9 cm/sec] than that of tasks 1 and 2. Task 3 provided moderate to good reliability [session1: ICC = 0.77; session2: ICC = 0.708]. Although the ICC values were >0.75, task 3 was not considered to have a good reliability because the range of 95% CI was wide [session 1: CI = 0.49–0.93; session 2: CI = 0.423–0.894] and SEM was high [0.95–1]. Portney and Watkins (2000) recommended that the ICC values for clinical measurement should be ≥0.90, implying that this task does not provide a reliable measure.

Although task 4 [EC1L] was performed by seven children in the first session and by ten children in the second session, only two recordings were included in the analysis. The ICC value of task 4 in session 1 was 0.866, which reflects good reliability; however, the range of CI was wide [0.462–0.975]. The ICC value of task 4 [EC1L] in session 2 was 0.426, which reflects poor reliability with a poor range of CI [-0.2–0.82]. Moreover, the SEM in both sessions was different [session 1: 0.96; session 2: 2.17]. This may be owing to the significant variability noticed with the repeated measures of the ANOVA F-test. It can be concluded that standing on one leg for 10 sec is not a practical test of balance for children between the ages of 6 and 12 years because it does not provide good reliable data.

5.7.2 Inter-session reliability

Data from both the sessions were tested for inter-session reliability (**Table 5.5**) and an analysis of the MDC between the sessions was conducted. The reliability of the WBB between sessions was found to be excellent during double stance both with eyes open and eyes closed [Task 1: ICC = 0.961; Task 2: ICC = 0.958]. These reliability values were with 95% CI [0.868–0.988] and an MDG of 0.4. This means that a double stance on the WBB provides excellent reliability with high confidence and minimum change across sessions. During the single stance, the reliability values were [Task 3: ICC=0.65; Task 4: ICC= 0.794], which reflects good reliability between sessions; however, the confidence interval was wide for both tasks, that is, with eyes open and eyes closed [Task 3: CI= 0.17–0.88; Task 4: CI = 0.26- 0.96]. A change of 3.2 was detected across days, implying a high variability in measurements. This result is consistent with the results of inter-session reliability, which shows that a single stance is not appropriate for children.

Table 5.5: Inter-session [between sessions] reliability

Task		**Trails [n]**	**Mean**	**SD**	**ICC 1,3**	**Lower CI**	**Upper CI**	**SME**	**MDC**
1	**EO2L**	3 [12]	2.76	0.75	0.961	0.875	0.988	0.15	0.41
2	**EC2L**	3 [12]	2.92	0.78	0.958	0.868	0.988	0.16	0.44
3	**EO1L**	3 [10]	6.68	1.88	0.651	0.174	0.884	1.11	3.08
4	**EC1L**	2 [7]	9.71	2.56	0.794	0.260	0.960	1.16	3.22

EO2L= standing on both legs with eyes open, EC2L= standing on both legs with eyes closed, EO1L= standing on one leg with eyes open, EC1L= standing on one leg with eyes closed, SD= Standard deviation, ICC= interclass correlation coefficient, CI= confidence interval, SEM= standard errors of measurements, MDC= minimum detectable change.

5.8 Discussion

The present study aimed to check the reliability of the WBB measurements with a child population. The results of this study show that among school-age children, double stance on the WBB provides more rigorous reliability values than single stance. These results were consistent with previous studies (Clark et al. 2010; Chang et al. 2013; Larsen et al. 2014; Park & Lee 2014), which showed the WBB provides reliable COP length but the correlation values during single leg standing tasks which were lower than double-leg standing tasks. However, differences were observed between the reliability results of this study (**Table 5.5**) and previous studies (Table 3.2) across the testing tasks. This may be owing to the differences between the study's procedures in terms of age group {adults or children}, the software connection, the statistical analysis and the COP length calculations {length per time or total length}.

There has been a high variability during the single leg standing data, which agrees with Park & Lee (2014) who showed that double stance tasks have shown a strong correlations reliability whereas single leg stance tasks have shown moderate correlations. Although this variability in data could be attributed to the fact that the WBB lacks the potential to detect postural changes during single leg stance. However, the COP length and velocity calculated from the WBB data was highly correlated with the COP length and velocity calculated from the force plate during single-leg standing (Huurnink et al. 2013). This means that the variable data during single leg stance was due to intra-subject variability and the WBB quantify COP trajectory accurately during single-leg stance balance tasks. However, the results of this study showed poor inter-session reliability during the single leg standing tasks, owing to the difficulty of the task for children.

To the author's Knowledge during conducting the present study, it was the first to test the reliability of the WBB in assessing the standing balance of children, however at the present new study by (Larsen et al. 2014) was found in literature. Larsen et al. (2014) has tested children aged between 10 and 14 years whereas this study tested children aged between 6 and 12 years. Although both were conducted with children, older children may behave differently than younger children due to the development of balance. In addition, this study tested the reliability of WBB data within the same day and between different days, unlike the Larsen et al. (2014) which only tested the validity and reliability of WBB data within one session only. Furthermore, standing in one leg with eyes closed was not tested by Larsen et al. (2014) which indicates the difficulty of such task. Even though, Larsen and colleagues (2014) found larger variations in the single leg stance tests, which is consistence with the results of the present study.

This study has a few limitations that will affect the generalization of its results. The first limitation is the disrupted connection between the WBB and MATLAB®, which led to some variability between the recordings and yielded different COP length calculations based on time unit. The second limitation is the sample size. This study had only 12 participants and the results of task 4 were based on the recordings of the 7 children who could successfully perform all tasks on both the test days. This resulted in missing data. Nevertheless, Bonett (2002) has proposed a formula to calculate future sample size requirements for an estimation of intra class correlations with desired width (Bonett 2002). By using this formula with the ICC values results in this study, the sample size required to test reliability of COP length during standing on both legs with eyes open or closed is 12 participants. However, with the variable data during standing on one leg, the sample size required to test the reliability of COP length with a desired width of 0.3 is 25 participants.

5.9 Conclusion

The WBB is a high technology, portable, low-cost, commercially available tool that has a valid use in assessing standing balance. This study shows that the WBB provides reliable outcomes of COP length when assessing double stance in TD children. It is a valid and reliable tool for assessing balance and tracking progression. However, the WBB is not recommended for single stance assessment with children because of the poor reliability results obtained in such cases. Before using the WBB in clinical settings to assess the standing balance of children with balance impairments, further research needs to be conducted to investigate the reliability of different standing tasks among such children.

This chapter included details of the reliability study which was conducted on the WBB's COP length with TD children. This study also included a pilot work to test the methods and procedures suitability for participants. Then a reliability testing of the WBB's data during different standing tasks for TD children. Findings from this study was discussed in relation to literature and gave reference data of COP length collected from WBB for TD children. The next chapter will include another reliability study was conducted with children with CP.

Chapter 6: Intra-session and Inter-session reliability of the WBB when assessing standing balance in children with Cerebral palsy

6.1 Introduction

The use of the WBB to measure standing balance with COP parameters has been a valid and comparable measure to laboratory based measures such as force plate analysis among healthy adults (Clark et al. 2010; Chang et al. 2013; Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Park & Lee 2014; Pavan et al. 2014; Scaglioni-Solano & Aragon-Vargas 2014; Pavan et al. 2015), older adults with total joint arthroplasty (Abujaber et al. 2015), adults with PD (Holmes et al. 2013b), and adults post stroke (Bower et al. 2014). Additionally, the WBB has demonstrated excellent reliability to measure parameters of standing balance, such as COP length, with adult population (Clark et al. 2010; Clark et al. 2011; Chang et al. 2013; Bower et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Abujaber et al. 2015).

The reliability of WBB's COP data was tested with TD children in the previous chapter (Chapter 5), and showed that the WBB provides a reliable measure of standing balance in TD children. In addition, recently, Larsen et al. (2014) reported that the WBB is a valid and reliable tool for assessing standing balance in children. These reliability findings may however not be applicable to children with CP due to differences in standing balance postures. However they provided a reference data of COP length for TD children, which are essentials for using the WBB in examining children with CP. However, to the author knowledge there is no studies that have investigated the reliability of WBB for assessing COP length during standing for children with CP. Therefore, it is important to fill this gap in literature and have reference data of COP length for children with CP. In addition, the WBB's calculated COP length will be used for standing balance assessment, following Wii Fit training for children with CP in the following feasibility study (Chapter 7). Therefore, the reliability of the WBB for measuring COP length in children with CP had to be investigated first.

This chapter includes a report of findings from assessing reliability of the WBB when used to measure COP path length in children with CP. However, owing to time limitations, this study was conducted in the same time with the feasibility study (Chapter 7), as children with CP undertook two baseline measurements before the training with Wii Fit balance games.

6.2 Aims

1- To test the intra-session {within session} and inter-session {between sessions} reliability of the WBB to measure COP path length in children with CP.

2- To compare results of COP length measured by the WBB between children with CP and TD children.

6.3 Methodology

6.3.1 Sample and recruitments

The sample size was composed of twelve children with CP, who were included based on the inclusion criteria (section6.3.2). The recruitment process took a place between July 2013 and Sep 2014 through different sites in both countries the United Kingdom and Saudi Arabia (Figure 6.1).

From **Southampton, United Kingdom,** six children with CP were recruited through two sites; 1) the Rose Road Association [RRA], which is a charity providing activities for children with disabilities in Hampshire, and 2) the Buzz network, which is a network funded by the Southampton city council for all parents of children with disabilities in Southampton.

Following the faculty of health sciences ethical approval (Appendix 13) and agreements with both RRA and the Buzz network, paid postage invitation packs were sent to families with children with physical disabilities through the RRA and the Buzz network. Each invitation pack included a letter of invitation (Appendix 14), parents' information sheet (Appendix 15), children's information sheet (Appendix 16), GMFCS Family Report Questionnaire (Appendix 17), reply slip (Appendix 18) and FREEPOST envelope. Both the information sheets clearly indicated that only children with a diagnosis of CP could participate in the study. The GMFCS Family Report is a valid and reliable report for the families to identify the gross motor functional level of a child with CP. Moreover, an electronic advert, including information about the study with the researcher's contact details, was posted in the electronic newsletters issued by the RRA and Buzz network (Appendix 19). The same advert was also posted in a public newspaper in Southampton 'the Daily Echo newspaper'. This process took a place between July 2013 and March 2014.

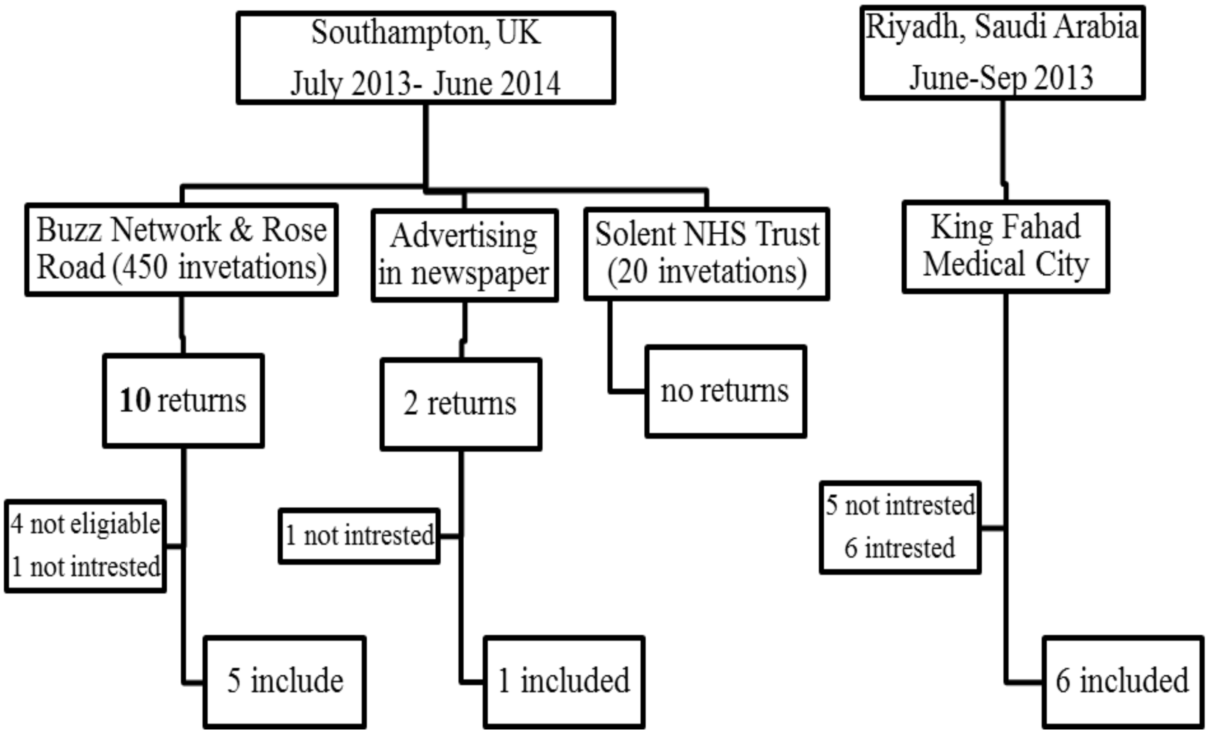


Figure 6.1: Recruitment process diagram

In addition, recruitment was continued through the National Health Services [NHS] in UK, in particularly the Solent NHS trust, which is the NHS community physiotherapy service for children in Southampton. Following the NHS ethical approval (Appendix 20 and Appendix 21) and agreements with Solent NHS trust, paid postage invitation packs were sent to families with children with CP, who were identified as receiving community physiotherapy service in Southampton. Each invitation pack included a letter of invitation (Appendix 14), parents' information sheet (Appendix 15), children's information sheet (Appendix 16), GMFCS Family Report Questionnaire (Appendix 17), reply slip (Appendix 18) and FREEPOST envelope. This process took a place between March 2014 and June 2014. However, no participants were recruited from Solent NHS trust.

Due to the limited number of participants recruited from the centres mentioned above, plans were made to commence recruitment in **Riyadh, Saudi Arabia**. Six children with CP were recruited from the paediatric out-patient physiotherapy clinic at King Fahad Medical City [KFMC] in Riyadh, Saudi Arabia.

Following ethics approval (Appendix 22) and agreements with the paediatric physiotherapists who work in paediatric out-patient clinic at KFMC, invitation packs were distributed to families with children with CP, who are attending the clinic and identified by the physiotherapists as candidates to the study. Each pack has included a letter of invitation (Appendix 23), parents' information sheet (Appendix 24), children's information sheet (Appendix 25), and the contact details of the researcher. There was no GMFCS Family Report Questionnaire or reply slip because children were identified by the paediatric physiotherapist. All the sheets in the pack were translated to Arabic language. Recruitment in Riyadh took a place between June 2014 and Sep 2014.

6.3.2 Inclusion/exclusion criteria

Inclusion criteria:

1. Children who have been diagnosed with hemiplegia or diplegia CP.
2. Children aged between 6 and 12 years.
3. Children who are classified at levels I, II or II on the GMFCS.
4. Children who can stand independently for 3 min without any support.
5. Children who have not undergone any spinal or lower extremity surgery during the last three months.
6. Children who do not have hearing impairment.
7. Children who have normal vision or whose vision has been corrected to normal vision.
8. Children who can understand and follow verbal commands.

Exclusion criteria:

1. Children who have a diagnosis of quadriplegia or athetoid CP.
2. Children who are classified at levels IV and V on GMFCS.
3. Children who experience uncontrolled seizures.
4. Children who have had an ear infection during the last six weeks.
5. Children who have taken botulinum toxin injections [type A] during the last six months.
6. Children who are currently participating in another research involving balance training.

6.3.3 Consents

Based on the reply slip and the agreement to be contacted, children and families were contacted to arrange date and time for the first initial assessment session. During the first session, the researcher has discussed and explained the study procedures to parents and children. When the parents have agreed for their child to participate they were asked to sign a consent form (Appendix 26 and Appendix 28). After that the children filled in the assent form for children (Appendix 27 and Appendix 29) if they are happy to participate. Both parents' and children's consents forms were translated to Arabic language (Appendix 28 and Appendix 29) for participants from Saudi Arabia. Ethical approval was obtained from the ethics committee of the Faculty of Health Sciences at University of Southampton (Appendix 13), National Research Ethics Service [NRES] Committee North West (Appendix 20) with the research and development department at Solent NHS trust (Appendix 21), and Institutional Review Board at KFMC (Appendix 22).

6.3.4 Settings

6.3.4.1 Equipment setting

The WBB and the laptop were connected through a Bluetooth dongle. The WBB was calibrated first with no weight applied then with five kg weight placed at the centre of the WBB. The extracted data from the WBB's sensors were recorded using MATLAB® software. Further details about the WBB and MATLAB® connection and the calculation of COP length was mentioned in section 5.4.5.2.

6.3.4.2 Lab setting

Data collection sessions were held at a room in building 45 at the University of Southampton [Southampton, UK] or at a room in paediatric out-patient physiotherapy clinic at KFMC [Riyadh, Saudi Arabia]. The rooms for data collection were equipped with a bathroom scale and a meter tape measurement attached to the wall from the floor. These were used to record the weight and height measurements of each child.

The WBB was placed on the floor, in the middle of the room, and surrounded by mat sheets (Figure 6.2). Then, the WBB was covered with a rubber cover to prevent children from slipping and this cover had foot marks to standardise the feet position of the children. A chair was placed one meter behind the WBB and the mats for children to sit on and rest. In addition, children were wearing a safety-handling belt around their waist for the physiotherapist to be able to handle them in the event of loss of balance or fall.

Figure 6.2: Lab setting

6.3.5 Procedures

The participants attended two assessment sessions in one week. The first session was the initial child's assessment with first set of measurements 'day one measurements'. The child's assessment was carried out by a trained and qualified physiotherapist and documented with the child assessment form (Appendix 30 and Appendix 31). The assessment form has two parts; the first part includes the child demographic information, weight, height, medical history filled by the parents, and the second part includes muscle tone of lower limbs, posture description, and the ability of the child to perform few functional tasks, like walking or standing filled by the physiotherapist.

Based on results from the reliability study presented in Chapter 5, single leg stance was not a practical test for children and it produces poor reliability results of low ICCs. Therefore, children with CP were asked to remove their shoes or any foot orthoses and step onto the WBB to perform two tasks; standing on both legs with their eyes open [EO2L] and eyes closed [EC2L] for 30 seconds. Each task was repeated thrice with a rest period of 30 seconds between each repetition. Children were instructed to stand as still as possible. The same procedure was repeated in the second session, day two measurements', as well as the other outcome measures [the PBS and the TUG] for the feasibility study in Chapter 7 (section 7.4.5).

6.3.6 Data analysis

All the recorded data was processed using a MATLAB® algorithm (Appendix 11) to calculate the COP path length per time unit 'cm/sec'. Data was analysed using IBM SPSS 20. The Shapiro-Wilk test was used to test the normal distribution of the data. Descriptive statistics were used to describe the mean and SD of the data. ANOVA F-test was used to test the significant variability between the three repetitions of each task in each session. The [ICC $_{1,1}$] with 95% CI and the SEM were used to test intra-session reliability {within each session}. The same tests were used for the inter-session reliability {between sessions} in addition to the MDC. Further details was mentioned in section 5.6.2. Statistical differences between TD children and children with CP during double – leg standing with eyes open and closed tasks were tested using two-sample t-test (two tail, unequal variances).

6.4 Results

The study was conducted from Aug 2013 to Sep 2014. Twelve children with CP completed the study. Participants included five boys and seven girls, with a mean age of 8.7±2.2 years, mean weight of 31.9±14.2 kg, mean height of 127±16.8 cm, and mean BMI of 18.8 ±4.1. Six children were recruited from Southampton, UK and six children were recruited from Riyadh, Saudi Arabia. The GMFCS levels (Figure 2.1) were between level I and level III; six children were at level I, three children were at level II, and three children were at level III. Their other demographic characteristics and the number of therapy sessions they receive each week are presented in Table 6.1.

Each child completed two testing sessions. Each session included six recordings {two tasks repeated thrice each}. Each recording was initially saved in a notepad data file and subsequently downloaded to a MATLAB® algorithm, which calculated the COP length [cm/sec] for each recording (Appendix 11). Three COP length recordings for each child were grouped for each task. The row data of COP length recordings is presented in table A37.1 (Appendix 37). Following the Shapiro-Wilk test, the data for each task was found to be normally distributed and the repeated measures of the ANOVA F-test showed no significant variability between the three COP length recordings.

6.4.1 Intra-session reliability

Data from the first and second sessions were tested for intra-session reliability together (Table 6.2). Only one child had two repetitions of task [EC2L], therefore the results from eleven children with a complete set of data is presented.

Table 6.1 : Demographic characteristics of children with CP [Chapter 5 and 6]

ID	Age	Weight	Height	BMI	Gender	GMFCS level	CP description	PT sessions/week	Other therapies
1	6	19.5	110	16.1	F	II	Diplegic	2	HR
2	7	20.3	117	14.8	M	I	Hemiplegic	-	-
3	10	31.9	140.5	16.2	F	I	Diplegic	-	OT & swimming
4	8	45.5	144.5	21.8	F	I	Hemiplegic	3	OT, HR & dancing
5	12	51.8	155	21.6	M	III	Hemiplegic	2	BT
6	6	20	112.5	15.8	M	I	Hemiplegic	3	OT
7	7	17	107	14.8	F	I	Diplegic	1	-
8	7	18	113	14.1	F	II	Diplegic	2	-
9	8	30.9	118	22.2	F	I	Diplegic	1	-
10	11	60	150	26.7	M	II	Diplegic	1	-
11	12	35.4	124	23	F	III	Diplegic	-	-
12	10	32	133	18.1	M	III	Hemiplegic	1	OT & ST
Mean	**8.7**	**31.9**	**127**	**18.8**	**-**	**-**	**-**	**-**	**-**
SD	**2.2**	**14.2**	**16.8**	**4.1**	**-**	**-**	**-**	**-**	**-**

BMI=Body Mass index, F= Female, M=Male, GMFCS= Gross Motor function classification system, PT= Physiotherapy, OT= Occupational therapy, HR= Horse riding, BT= Behavioural therapy, ST= Speech therapy

The results from both sessions indicated that standing with eyes open showed good to excellent reliability [ICC=0.879-0.897] with a good 95% CI [0.75-0.95] and a low SEM [0.28-0.36]. The mean Cop length measured for children with CP during double stance with eyes open was 3.3 to 3.5 ±1 cm/sec. Nevertheless, standing on both legs with eyes closed has shown moderate reliability [ICC= 0.63-0.58] with a wide range of 95% CI [0.29-0.86] and a higher SEM [0.6-0.8] than standing with eyes open. However, it did not reach the clinically accepted reliability [ICC≥0.75]. Though, the mean COP length measured during double stance with eyes closed was 3.7 - 4 ±1 cm/sec, which was quite similar to mean COP length during double standing with eyes open 3.3 - 3.5±1.

Table 6.2: Intra-session reliability for children with CP

Session	Task	Trials [n]	Mean	SD	ICC 1,1	lower CI	upper CI	SEM
Day 1	EO2L	3 [11]	3.34	0.90	0.897	0.751	0.968	0.289
	EC2L	3 [11]	3.67	1.01	0.632	0.299	0.869	0.610
Day 2	EO2L	3 [11]	3.49	1.06	0.879	0.722	0.959	0.368
	EC2L	3 [11]	4.04	1.32	0.582	0.234	0.846	0.853

EO2L= standing on both legs with eyes open, EC2L= standing on both legs with eyes closed, SD= Standard deviation, ICC= interclass correlation coefficient, CI= confidence interval, SEM= standard errors of measurements

6.4.2 Inter-session reliability

Data from both the sessions were tested for inter-session reliability (Table 6.3) and an analysis of the MDC between the sessions was performed. The reliability of COP length from WBB for children with CP between sessions was found to be excellent during double stance both with eyes open [ICC=0.92] with a narrow range of 95% CI [0.75-0.98], low SEM [0.27] and low MDC [0.74]. However, during double stance both with eyes closed the reliability was shown to be moderate [ICC=0.58] with a wide range of 95% CI [0.05-0.85], higher SEM [0.69] and MDC [1.9]. This high variability between measurements across days has provided unacceptable level of reliability. Portney and Watkins (2000) recommended that the ICC values for clinical measurement should be ≥0.90, implying that this task does not provide a reliable measure.

Table 6.3: Inter-session reliability for children with CP

Task	Trials [n]	Mean	SD	ICC 1,3	lower CI	upper CI	SME	MDC
EO2L	3 [12]	3.4	0.94	0.919	0.754	0.976	0.268	0.744
EC2L	3 [12]	3.88	1.07	0.575	0.054	0.854	0.695	1.927

EO2L= standing on both legs with eyes open, EC2L= standing on both legs with eyes closed, SD= Standard deviation, ICC= interclass correlation coefficient, CI= confidence interval, SEM= standard errors of measurements, MDC= minimum detectable change.

6.4.3 Difference between TD children and children with CP

The children with CP in this study were aged matched with the TD children in the study of Chapter 5, as both had similar mean of age 8.7 ±2.2 years and 8.5 ±1.9 years, respectively. This allow for a comparison of the COP length between the two groups. The COP data recordings and COP length [cm/sec] calculations from the WBB during double stance with eyes open and eyes closed on the first session, were used for comparison between TD children and children with CP (Table 6.4).

The mean COP length measured for children with CP during double stance with eyes open and eyes closed was 3.31 ± 0.87cm/sec and 3.66 ± 0.88 cm/sec, respectively. Whereas, the mean COP length measured for TD children during double stance with eyes open and eyes closed was 2.79 ±0.72 cm/sec and 2.89 ± 0.81 cm/sec, respectively. It can be seen that the difference in COP length between TD children and children with CP during standing with eyes open and eyes closed [0.52 cm/sec and 0.77 cm/sec, respectively] was less than one cm/sec.

However, the statistical test, two-sample t-test (two tail, unequal variances), showed a significant difference between children with CP and TD children during double –leg stand with eyes closed [$p=0.036$]. whereas, during double –leg stand with eyes open the difference was not significant [$p=0.123$]. This finding means that those children with CP in the present study at GMFCS level I, II and III have a similar COP length during double stance with eyes open to TD children.

Table 6.4: The COP length differenceses between TD children and children with CP

COP length [cm/sec]	EO2L		EC2L	
ID	**TD children**	**Children with CP**	**TD children**	**Children with CP**
1	2.83	3.53	2.71	4.68
2	2.63	3.33	2.31	4.18
3	1.35	2.61	1.41	2.97
4	2.95	2.11	3.24	2.87
5	3.64	3.02	3.77	3.51
6	2.75	4.34	2.93	4.5
7	3.29	4.19	3.39	4.15
8	2.78	3.68	2.86	3.96
9	1.87	2.37	2.18	2.68
10	2.27	2.06	2.17	1.92
11	3.19	4.18	3.28	3.91
12	3.94	4.35	4.44	4.64
Mean	2.79	3.31	2.89	3.66
SD	0.72	0.87	0.81	0.88
P value	**0.123**		**0.036***	

EO2L= standing on both legs with eyes open, EC2L= standing on both legs with eyes closed, SD= Standard deviation

***Significant difference of ≤0.05**

6.5 Discussion

The aim of the present study was to assess the reliability of the WBB measurements in children with CP. The results showed that among children with CP, double-leg standing on the WBB with eyes open provides more rigorous reliability values than with eyes closed. To the author's knowledge, no study has investigated the reliability of WBB in measuring COP length during standing for children with CP so these findings are novel and the discussion of present findings with published work is limited.

These results were in agreement with the results from Chapter 5 (section 5.7). Both studies found that double leg standing on WBB with eyes open provides an excellent reliability of COP length. This might be due to the staidness of the task where it does not require further control to maintain balance. In contrast, tasks like standing with eyes closed or standing on one leg requires higher levels of postural control to maintain balance during standing. In that sense children with CP may not behave the same during each recording and eventually the COP lengths, recorded each time, were not consistence causing high variability and wide range of confidence interval. In addition, children with CP rely on their visual sensation to compensate the lack of proprioception sensation (Wingert et al. 2009) in order to maintain balance during standing, which means that standing with eyes closed is a challenging task to perform.

Furthermore, the high variability of COP length during standing with eyes closed for children with CP is similar to the variability seen during single leg standing for TD children. As discussed earlier (section 5.8), single leg standing variability was also seen in different studies conducted with adults (Clark et al. 2010; Huurnink et al. 2013; Park & Lee 2014) and children (Larsen et al. 2014). Even though, this COP parameter variability from the WBB was highly correlated to the ones calculated from the force plate during single-leg standing (Clark et al. 2010; Huurnink et al. 2013; Larsen et al. 2014; Park & Lee 2014). This means that the WBB quantify COP trajectory during different standing tasks accurately and the variable data was due to the difficulty of the task. However, standing with eyes closed for children with CP has not yet been tested for validity and the variability in the recordings during this task might be due to the limited technology of the WBB to capture COP with more sway of children with CP. Though, this explanation was not evident in the present study and needs to be investigated in further studies.

The present study had only twelve participants and the results of intra-session were based on the recordings of the eleven children who could successfully perform each task three times. Nevertheless, Bonett (2002) has proposed a formula to calculate future sample size requirements for an estimation of interclass correlations with desired width(Bonett 2002). By using this formula with the ICC values results in the present study, the sample size required to test reliability of COP length during standing on both legs with eyes open is eleven participants. However, the sample size required to test reliability of COP length during standing on both legs with eyes closed with a desired width of 0.3 is 78 participants. Therefore, the results of this study confirms that the WBB can provide reliable data of COP length for children with CP during standing with eyes open, though during standing with eyes closed it did not show acceptable reliability level. However, more studies with larger sample will be required to provide more information on the reliability of the WBB for assessing COP length in children with CP.

A limitation of the present study were; first, the disrupted connection between the WBB and MATLAB®, which led to some variability between the recordings and yielded different COP length calculations based on time unit. In addition, it was not clear if the variability seen between recordings was a combination of the child's lack of balance and difficulty to perform tasks or due to the limited technology of the WBB to capture COP capture COP when the child sway more. Another limitation was the small number of participants which would limit the generalisability of the findings.

6.6 Conclusion

The WBB is a high technology, portable, low-cost, commercially available tool that has a valid use in assessing standing balance. This study shows that the WBB provides reliable outcomes of COP length when assessing double stance with eyes open in children with CP. However, the WBB provided unacceptable level of reliability of COP length during standing with eyes closed. More developmental work is needed on the technology to improve reliability for assessing standing tasks with eyes closed. Further testing in larger samples and other clinical groups would provide more information on the clinical utility of the WBB.

This chapter included details of the reliability study which was conducted on the WBB's COP length with children with CP. This study was a repetition of the study in Chapter 5, with few changes. Novel findings from assessing reliability of the WBB when used to measure COP path length in children with CP was reported. This study was conducted alongside the feasibility study of the next chapter (Chapter 7), as children with CP undertook two baseline measurements before the training with Wii Fit balance games. The next chapter will include the feasibility study conducted with children with CP to test the effect of Wii Fit balance games on improving standing postural control and functional balance activity.

Chapter 7: The feasibility of evaluating the effect of Wii Fit balance games on standing postural control among children with cerebral palsy

7.1 Introduction

Balance training is one of the main goals of rehabilitation programmes for children with CP. This is because children with CP present with postural control deficits due to muscle tone impairments, musculoskeletal imbalances and conflicting sensations. These impairments make children with CP experience daily challenges in maintaining their balance, and this feeling of instability could lead to a preference for more sedentary activities.

Computerised balance training, particularly weight shifting, has been found to be clinically effective for children with CP (Hartveld & Hegarty 1996; Shumway-Cook et al. 2003; Ledebt et al. 2005; Woollacott et al. 2005). Other studies have shown that the use of virtual reality with balance training is effective in improving the functional balance mobility and walking ability of children with CP (Brien & Sveistrup 2011). Active gaming, such as Nintendo Wii Fit balance games, is a virtual reality tool that can be considered a balance training tool because the games require players to shift weight while playing. Existing studies conducted using the Wii Fit balance games have demonstrated the effectiveness of the games for balance training for adults and children with impaired balance. However, thus far, only four studies have been conducted to test the effect of Wii Fit balance games on balance in children with CP (Ramstrand & Lygnegård 2012; Sharan et al. 2012; Jelsma et al. 2013; Tarakci et al. 2013).

It was suggested that balance improvements shown in children with CP could be attributed to the task-specific training of Wii Fit. Moreover, Hornby et al. (2011) found that an adequate amount of task-specific training can facilitate the plasticity of neuromuscular systems, which may lead to functional improvements. When considering weight-shifting practice as a task-specific practice, standing balance can be improved (Hartveld & Hegarty 1996). However, additional research needs to be conducted to test this theory using Wii Fit games. In addition, following Wii Fit training, improvements were seen in children with lower limb amputations in terms of decreased COP sway area (Andrysek et al. 2012). This means that playing Wii Fit may have the mechanical effect of increasing postural control awareness. Furthermore, because Wii Fit games are played in a standing position, they stimulate different trunk muscles, thereby increasing standing stability. Therefore, Wii Fit can potentially improve both static and dynamic postural control in children with CP.

The training offered by Wii Fit games is highlighted in the repetitive weight shifting with visual and auditory feedback from an interactive environment. In addition, the Wii Fit games require cognitive demand, such as attention, planning, memory and decision making, to win games. This means that Wii Fit games are complex dual tasks, which involve cognitive and motor functioning, which could improve cognitive-motor learning. Furthermore, Wii Fit games provide augmented feedback of player movement that is represented either by character movement or by character surrounding environment. This feedback enhances motor learning during task training (which is weight shifting, and cognitive skill training such as learning how to weight shift to win the game). The ability to learn from Wii Fit games and to transfer learning to perform untrained motor task has been studied among adults with PD (Mendes et al. 2012). Mendes et al. (2012) identified a learning curve and learning deficits among adults with PD while playing Wii Fit games that required cognitive demand. In addition, adults with PD have demonstrated improvements in game scores after training, similar to healthy controls (Mendes et al. 2012). Furthermore, the Montreal Cognitive Assessment showed significant improvements immediately after Wii Fit training for adults with PD that were maintained for two months (Pompeu et al. 2012). This emphasises the potential cognitive-motor learning theory of training with Wii Fit games.

Despite the reported findings from the limited studies found in the literature, further research needs to be conducted to test the theory of using Wii Fit games as task-specific training for children with CP. In addition, due to the small size, homogeneity and lack of power of the sample in each of the studies conducted with children with CP, their results cannot be generalised. Three studies measured functional mobility in general and only one measured standing postural control in particular, which is usually measured by the COP parameters that reflect an individual's stability and standing balance control. This highlights the need to assess the usability and feasibility of implementing the Wii Fit balance games in rehabilitation as training tools for standing postural control and functional balance in children with CP. Furthermore, none of these studies had a randomised control group to show the pure effect of the Wii Fit balance games on static and dynamic balance. Due to the gap in the literature regarding the use of Wii Fit games as balance training rehabilitation tools for children with CP, an RCT is needed.

Therefore, this chapter will discuss the methodological feasibility study conducted to inform about the suitability of the methods and procedures for a future RCT with a larger powered sample. In addition, this study has tested the effectiveness of the virtual reality gaming system of Wii Fit and its balance games as a postural control training intervention for children with CP. This chapter will also report findings regarding implementing the Wii Fit balance games in the rehabilitation programme in terms of enjoyment, adherence and applicability of Wii Fit balance games for children with CP.

7.2 Aim and objectives

Test the methodological feasibility for conducting future RCT which will investigate the effect of the Wii Fit balance games training on standing postural control and functional mobility in children with CP.

Objectives:

1. Provide the preliminary results of the effect of the Wii Fit balance games on the standing stability, by using the WBB, and functional balance mobility, by using the PBS and TUG, in children with CP.
2. Estimate recruitment rate to help in planning recruitment for the future RCT.
3. Test the methodology in terms of the delivery of the Wii Fit games, including the duration and intensity of the Wii Fit training and the convenient research settings.
4. Record the adherence rate including frequency and duration of each game, in addition to monitoring of adverse events.
5. Gather feedback from children regarding enjoyment level, using the Physical Activity Enjoyment Scale [PACES], and the most games played to identify the suitable suggested games.

6. Refine the selection of outcome measures for the ultimate RCT which will test the effectiveness of the Wii Fit balance games.

7. Calculate sample size for a larger RCT based on the standard deviation of potential primary outcome measure.

8. Assess the feasibility of implementing the Wii Fit games as a rehabilitation tool and the WBB as an assessment tool for children with CP in clinical and research settings.

7.3 Study design

This feasibility study included one group of participants and the quasi-experiment pre- and post-test design, was used. This design was selected because quasi-experimental studies usually aim to evaluate interventions because they demonstrate causality between an intervention and an outcome. In addition due to the small sample size participants will act as their own controls. Furthermore, this design has the statistical advantage of being able to detect changes in the mean values as a result of any intervention.

7.4 Methods

7.4.1 Sample and recruitments

Due to the limited research conducted in this felid, a power calculation of sample size was inappropriate (Julious 2005). Therefore this feasibility study was conducted with a sample of 12 children with CP. The recruitment process was the same as described in Chapter 6, section 6.3.1.

7.4.2 Inclusion/exclusion criteria

The same inclusion & exclusion criteria mentioned in Chapter 6, section 6.3.2. In addition, children whose safety was questionable while they played games {e.g., had a high risk of falling} or stated discomfort during the assessment session will be excluded.

7.4.3 Consents

Procedure for giving written consent has been described earlier in Chapter 6, section 6.3.3.

7.4.4 Procedures

7.4.4.1 Initial assessment

On the first session, following consents, the child's initial assessment was carried out by a trained and qualified physiotherapist and documented on the child assessment form (Appendix 30 and Appendix 31). The assessment form has two parts; the first part includes the child's demographic information, weight, height, medical history {filled by the parents}, and the second part focusses on the muscle tone of lower limbs, posture description, and the ability of the child to perform functional tasks such as walking or standing {filled in by the physiotherapist}. This assessment was carried out to ensure the child's safety and ability to carry on the training sessions.

During the assessment session, children were asked to play the Wii balance games once to familiarize themselves with the games and to enable the researcher to evaluate their comfort levels with the games. At the end of the assessment, the children were asked if they have enjoyed plying the games or not and asked to provide reasons for their choices. These reasons may be physical pain, emotional discomfort from the games feedback, or the loss of interest in all games or one of them. These reasons were considered before including or excluding the child from the study.

7.4.4.2 Settings

7.4.4.2.1 Equipment settings

Following the guidelines of Nintendo Wii operation manual (Nintendo 2008), the Wii console was connected to the TV with video-audio cable and connected to the sensor bar placed on top of the TV (**Figure 3.1**). The console has the Wii Fit game disc on the DVD drive. The Wiimote and the WBB both synchronised with Wii console wirelessly via Bluetooth. The WBB was placed in front of the TV with a distance of one meter away (Figure 7.1).

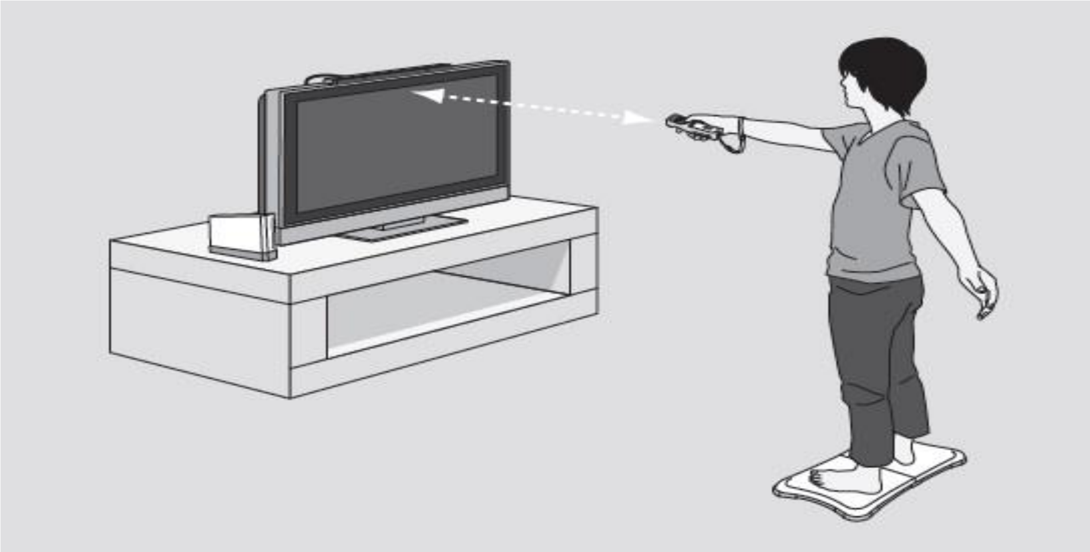


Figure 7.1: Nintendo Wii operation manual guidelines for set up (Nintendo 2008)

7.4.4.2.2 Lab settings

All assessment and training sessions were held at a room in building 45 at the University of Southampton {Southampton, UK} or at a room in paediatric out-patient physiotherapy clinic at KFMC {Riyadh, Saudi Arabia}. The room was equipped with a Nintendo Wii console, Wii Fit game, Wii balance board, TV screen and protective rubber mats around the WBB.

For the children’s safety, the WBB was covered with a protective rubber cover to avoid slipping, and protective mats were placed around the WBB in a space cleared from any objectives. A chair with arm support was placed behind the WBB for the child to sit on during rest. In addition, children wore a safety-handling belt around their waist for the physiotherapist to support them in the event of loss of balance or fall (Figure 7.2). Parents were asked kindly to attend all sessions with their children without the other siblings to avoid the child’s distraction. Children were giving the option of stopping the session at any time they feel fatigued, distressed, or uncomfortable.

Figure 7.2: Lab settings for the child's safety during playing Wii Fit

7.4.4.3 Intervention

The intervention was playing selected games of Wii Fit balance games. Games were played in randomised order according to the child's preference. Each game was played three times with a rest of 30 sec in between, and a rest of one min between games. Rest periods were extended if needed. The total time of each training session was 30 min. The Wii Fit balance games were selected because they require children to either shift their weight side to side or in multiple directions. Children were instructed to stand on the WBB without any shoes or foot outhouses. Children were given the instructions for each game how it is played and how to get the score of the game. Each child was asked to attend either 12 training sessions {three sessions per week} or eight training sessions {two sessions per week} for duration of four weeks. This option was provided parents and children in order for them to choose which option was more feasible to them to adhere to.

The main four selected games were the following;

1- Soccer heading; the player in this game tries to hit the footballs and avoid other objects like shoes or panda heads. The number of balls the player hits is the score of the game. This game requires shifting weight side to side while standing on WBB. The time duration for this game was 1-2 min (Figure 7.3 A).

2- Penguin slide; the player in this game tries to slid the iceberg for the penguin to capture the flying fish. The number of fishes the penguin gets within 60 seconds is the score of the game. It requires shifting weight side to side while standing on WBB. The time duration for this game was <1 min (Figure 7.3 B).

3- Ski Slalom; the player in this game ski between marked gates, with a red dot in blue circle to indicate speed needed. The games requires shifting weight side to side and in front to maintain the red dot, which represents COP, in the blue circle. This game has the benefit of visual feedback. The number of times the skier skipped a flag is multiplied by the speed of the skier to give a total score of performance. The time duration for this game was 1-2 min (Figure 7.3 C).

4- Table tilt; the player in this game tries to move the table platform in order to drop the balls in the table hols. It requires shifting weight in all planes as table will tilt along with player’s movement. This game has levels starting with level one, one ball in one hole, the challenge increase by increasing the number of balls. With each level there is a timer, starting at 60 seconds for level one, and the time decrease with each level as a challenge. The number of levels achieved with the time is calculated to provide a score of this game. The time duration for this game was 2-3 min (Figure 7.3 D).

In addition to these four games described above, children were given the option of playing two other games if they do not prefer any two of the previous games. The following games were selected to be optional because they have the same training technique of weight shifting;

5- Tightrope Walk; the player in this game walks across a tightrope between two buildings and jumps over obstacles. It requires shifting weight side to side while standing on WBB to mimic walking, however during jumping the player needs to flex and extend knees quickly. Time is displayed with count down as the score of this game is how fast the player completed the activity. There was a lot of instructions displayed while playing such as informing the player of where to shift weight to regain balance. The time duration for this game was2 min (Figure 7.3 E).

6- Balance Bubble; the player in this game is inside a bubble and tries to navigate down the river carefully to avoid being popped by obstacles such as the walls, rocks and bee. It requires shifting weight in all planes as bubble will move in all directions with player’s movement until the bubble reach a rainbow. This game is scored by calculating the time determined to complete the activity. The time duration for this game is about 1 min (Figure 7.3 F).

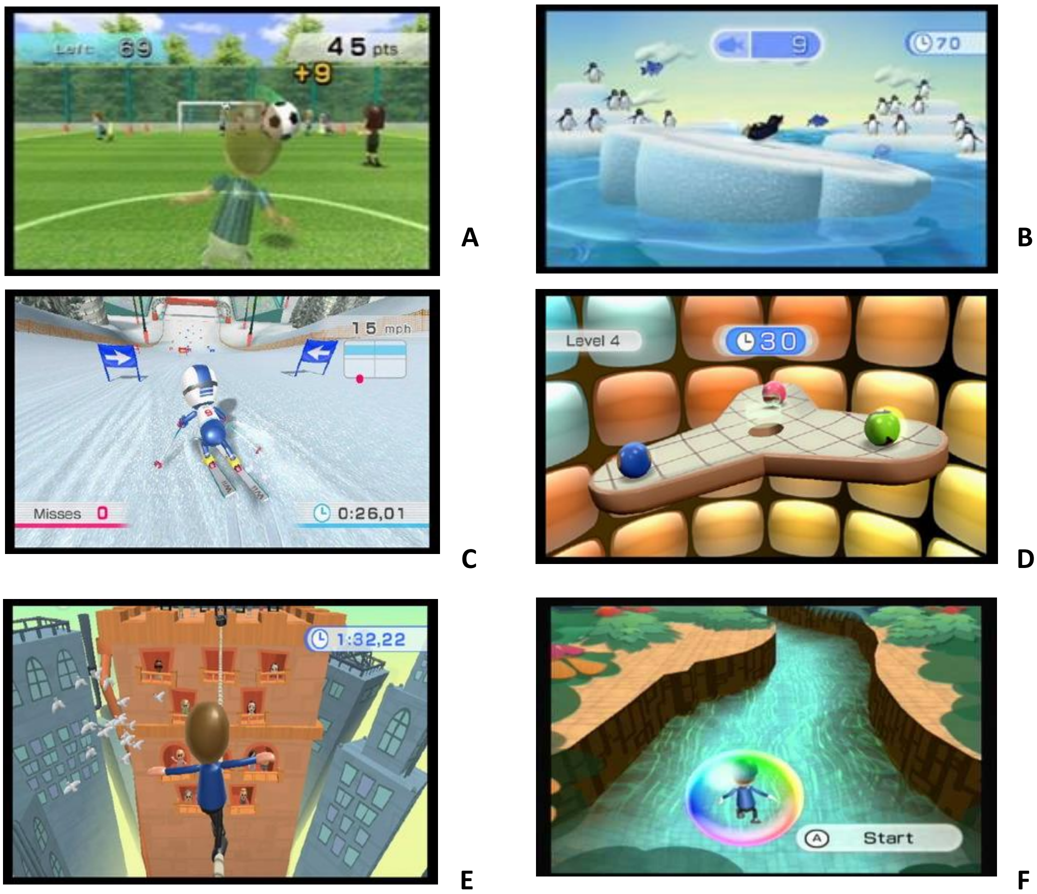


Figure 7.3: The Wii fit balance games selected for intervention

The Wii Fit training sessions were used in this study to train balance and postural control. However, this did not in any way replace the regular rehabilitation program that children with CP were receiving. As a precaution, children who had Wii Fit games at home were asked not to play the games during their training period of four weeks. Attendance to sessions were recorded by the researcher on the participant attendance sheet (Appendix 32), after every session to ensure consistency. The information recorded on the attendance sheet included date, time, games that the child played and the repetitions. By the end of each session, each child was given a sticker to place it on the child's attendance sheet (Appendix 33). In addition, at the last day each child was given a certificate as an appreciation for taking part in the study (Appendix 34).

7.4.5 Outcome measures

Outcome measurements were performed by the researcher in the presence of the physiotherapist in two sessions; pre- training and post-training. These measurement sessions were video recorded for a second assessor, who was blinded to dates on which measurements were taken. This was to avoid any bias from the researcher during outcome measurements. The second assessor was rating the child's performance in the PBS, and also assessed the consistency of the researcher's verbal commands during TUG and COP path length measurement by WBB.

7.4.5.1 Main outcome measurements

7.4.5.1.1 COP path length measured by WBB

The use of the WBB to measure standing balance with COP parameters has reported good validity and reliability when compared to the laboratory force plate in adults (Clark et al. 2010; Clark et al. 2011; Chang et al. 2013; Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Holmes et al. 2013b; Bower et al. 2014; Park & Lee 2014; Sgrò et al. 2014; Pavan et al. 2015) and children (Larsen et al. 2014). The previous developmental work (Chapter 4) found appropriate software [MATLAB®] to communicate with the WBB in order to capture real-time data and calculate COP path length per time unit [cm/sec]. Reliability testing of the WBB (Chapter 5) showed that the WBB can provide reliable measure of COP length [cm/sec] during standing for TD children. Therefore, the WBB was used in this study to measure balance pre- and post- Wii Fit balance training for children with CP. The reliability of the WBB when assessing COP path length in children with CP was tested (Chapter 6) in line with this study, as children with CP undertook two baseline measurements pre- Wii Fit balance training, due to time limitations.

Children were asked to stand on the WBB with both legs {without shoes or any foot outhouses} three times with eyes open and three times with eyes closed. Each recording was for 30 sec. The average of three repetitions was calculated for each task {eyes open and eyes closed}.

7.4.5.1.2 Pediatric Balance Scale

Berg Balance Scale has been shown to have high validity and reliability among adult population (Berg et al. 1989). As a result of the difficulties of using the BBS in children, the

Pediatric Balance Scale was published as a modification of the Berg Balance Scale (Franjoine et al. 2003). The PBS has the potential to discriminate between TD children (Franjoine et al. 2010) and children with mild to moderate motor impairments (Franjoine et al. 2003). The PBS is a 14-item rating scale which examines functional balance when performing activities of daily living tasks (Appendix 35). It takes 20 minutes to be administered and the highest score is 56. It has excellent test-retest [$ICC_{2,1}$= 0.92], interrater reliability [$ICC_{2,1}$ = 0.97], and intrarater reliability [$ICC_{2,1}$= 0.89-0.99] (Franjoine et al. 2010). The PBS total score is strongly correlated with GMFM-88 and GMFM-66 with a correlation coefficient [rs=0.9] and moderately [rs=0.7] correlated with the Paediatric Evaluation of Disability Index [PEDI] (Yi et al. 2012). It was reported that school-aged TD children aged six years and above had a PBS total score between 46 and 56 (Franjoine et al. 2010). Children with CP at GMFCS level I, II and III recorded a PBS total score range of 43-56, 20-54, and 12-35 respectively (Yi et al. 2012). A change in the total PBS score of 5.8 is considered the MCID (Chen et al. 2013).

7.4.5.1.3 Timed Up and Go

The TUG test is an assessment of functional dynamic balance that can be used for a population aged three years or older (Williams et al. 2005). During the TUG test, the child will be asked stand up from a chair, walk three meters with the use of assistive devices if needed {three meters are measured from the chair and marked by adhesive tape on the floor}, and return to the chair and sit on it. This was timed, the shorter the time spent to do the task, the better functional balance mobility. The TUG has an excellent interrater reliability with [ICC= 0.99] in children with CP aged between 3 and 12 years (Dhote et al. 2012). The MCID in TUG performance timing are 1.7, 1.2, 1.9 seconds for children with CP at GMFCS levels I, II and III respectively (Hassani et al. 2014).

7.4.5.2 Secondary outcome measures

7.4.5.2.1 Adherence

The adherence of children with CP to the training sessions was assessed by calculating the percentage of sessions attended over the four-week period and the number of sessions attended by each child as recorded in their respective attendance sheets (Appendix 32). The child’s adherence to the programme indicates his/her motivation. The number of times each game was played was recorded to indicate the child preference to which particular game.

7.4.5.2.2 Enjoyment

The PACES was used to assess the level of enjoyment experienced by children with CP while playing the Wii-fit balance games. The PACES is a valid measure of enjoyment of physical activity in children (Moore et al. 2009). It comprises16 items and a 5-point Likert-type scale {1 = 'Disagree a lot' to 5 = 'Agree a lot'}. Each item of PACES is a statement that begins with 'When I am physically active, …..'. In this study, the PACES was modified by changing the beginning of the statements to 'When I am playing the Wii Fit games, ….'. Children were asked to fill the PACES form at the end of their training program; if required, parents were allowed to assist their children in filling the form (Appendix 36). A score was calculated by averaging the scores of all the children for each individual item.

7.4.6 Data analysis

All statistical analyses were performed using SPSS [statistics 20]. Data from the pre- and post- training measurement sessions was examined for normality using the Shapiro-Wilk test. When data was normally distributed, a paired *t*-test was used for the ratio data from the WBB {the mean COP path length of three repetitions of two tasks}, TUG {time scale} and ordinal data from the PBS. When data was not normally distributed, then a nonparametric test, the Wilcoxon signed-rank test, was used. In addition, the PBS data from the researcher rating and from the blinded assessor rating was analysed for absolute agreement using Bland-Altman plots, the $ICC_{3,2}$ [two-way mixed] with 95% CI and SEM.

Both adherence and enjoyment are considered to be descriptive information. Participants' adherence was assessed by calculating the percentage of sessions attended over the four-week period. Enjoyment of the game was assessed by using the average PACES score of all children for each individual item.

7.5 Results

The study was conducted from Aug 2013 to Sep 2014. Eleven children with CP completed the study; only one child withdrew from the study when he could not attend for one week due to illness. Participants included five boys and seven girls, with a mean age of 8.7±2.2 years, mean weight of 31.9±14.2 kg, mean height of 127±16.8 cm, and mean BMI of 18.8 ±4.1. Six children were recruited from Southampton, UK and six children were recruited from Riyadh, Saudi Arabia. The GMFCS levels were between level I and level III; six children were at level I, three children were at level II, and three children were at level III. Their other demographic characteristics and the number of therapy sessions they receive each week are presented in Table 6.1. Table A37.1 is a detailed table of the row data used for analysis can be found in Appendix 37.

7.5.1 COP length by WBB

Based on the results of chapter 6, the COP length calculated during standing on WBB with eyes closed for children with CP did not show acceptable reliability level, and more studies with a larger sample of 78 participants is required. However, the WBB provides reliable outcomes of COP length when assessing double stance with eyes open in children with CP. Therefore, this section will only report the COP length during double stance with eyes open.

The COP length [cm/sec] calculated from the WBB at the second session was used for analysis and shown to be not normally distributed; therefore, a nonparametric test, Wilcoxon signed-rank test, was used (**Table 7.1**). The difference between pre- and post-training of COP length during standing on WBB with eyes open was not statistically significant [p=0.21] . Despite the lack of significance, the mean COP length at post-training was slightly higher than pre-training with a mean differences of [-0.75 ± 1.5] during eyes open. Additionally, there has been some improvements highlighted by a decreased COP length post-training in five participants [ID; 5,6,8,10,12] however, none has reached the MDC of 0.74 as reported in chapter 6.

Box plots were created to visually display the differences in COP length across the sample (Figure 7.4). There was an outlier [ID 11] who recorded a significantly longer COP length during standing with eyes open at post training in comparison to pre-training.

Table 7.1: Wilcoxon signed-rank test for COP length {pre- and post-training}

ID	Pre- training	Post- training	Differences
1	3.68	5.39	-1.71
2	4.22	-	-
3	2.46	3.63	-1.17
4	1.99	2.376	-0.39
5	2.8	2.76 *	0.04
6	4.46	4.12 *	0.34
7	3.89	3.95	-0.06
8	4.01	3.93 *	0.08
9	2.66	3.49	-0.83
10	2.07	1.96 *	0.11
11	4.76	9.6	-4.84
12	4.87	4.65 *	0.22
Mean	3.42	4.17	-0.75
SD	1.07	2.05	1.5
95% CI of differences			**0.27-(-1.76)**
P			**0.21**

CI= confidence interval, SD= standard deviation, P= significant value of ≤0.05

*** A decrease in the COP length per second at post-training shows improvement**

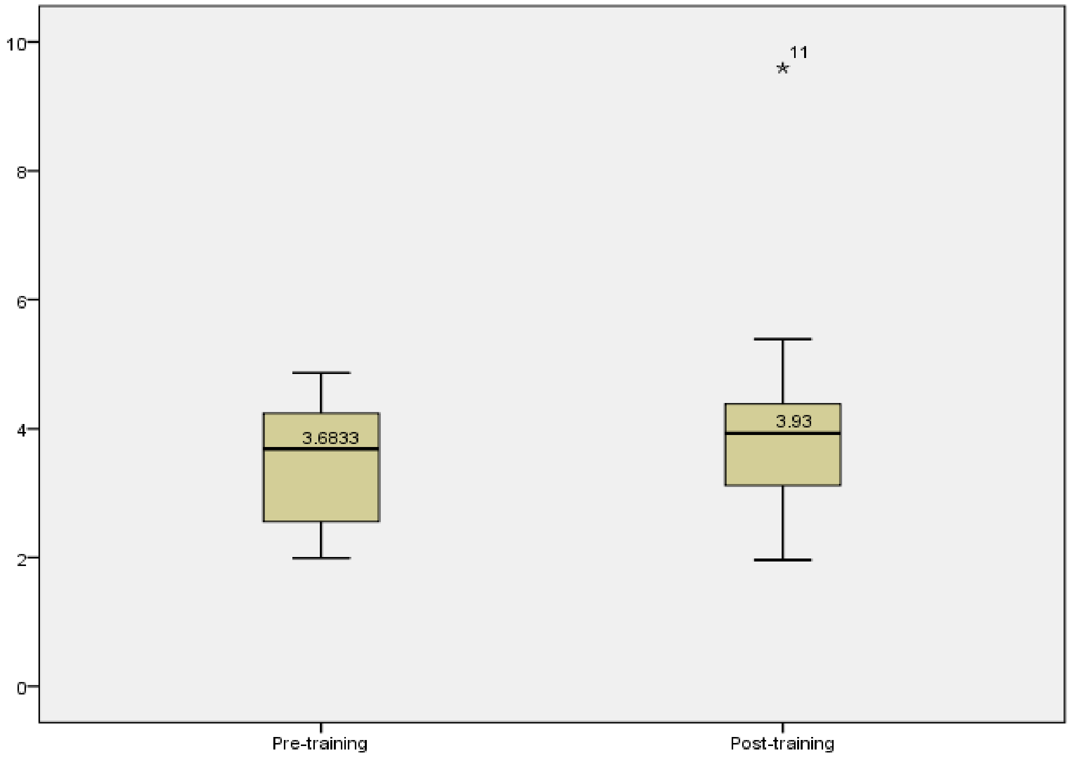


Figure 7.4: Comparison of pre-and post-training COP length during standing with eyes open

7.5.2 PBS

Data from the PBS was collected by two ratters; the researcher and the second assessor, who was blinded to dates on which measurements were taken. This was to avoid any bias from the researcher during outcome measurements. The agreement between the two ratters was tested with two-way mixed effect [ICC $_{3,2}$ = 0.892 and 0.857] for pre- and post-training respectively (Appendix 37, Table A37.2). In addition, Bland –Altman plots showed the mean difference between ratters at pre-and post-training measures were [0.18 and -1] respectively, which were very close to zero and within the limits of agreement [4.38 and -4, 4.2 and -6.2] respectively (Appendix 37, Graph A37.1). which is considered good ratter-reliability according to Portney and Watkins (2000). Therefore, the PBS data collected by the second assessor was used for the analysis.

The data from the PBS has shown to be normally distributed, therefore, paired t-test was used to analyse the difference between pre- and post-training of PBS scores (**Table 7.2**) and a box plot was used to show the difference across the sample (Figure 7.5). The mean difference between pre- and post-training of PBS scores was -0.18 ± 2.86 with a 95% CI [-

1.74-2.1]. It can be concluded that the total PBS scores of pre- and post-training were similar and the difference between them was not statistically significant [p=0.84]. Only four participants have shown improvements as an increase in the PBS score [ID; 3,4,5,8]. However, the minimum clinical importance difference in total PBS sores is 5.8 (Chen et al. 2013), which was not found in these results.

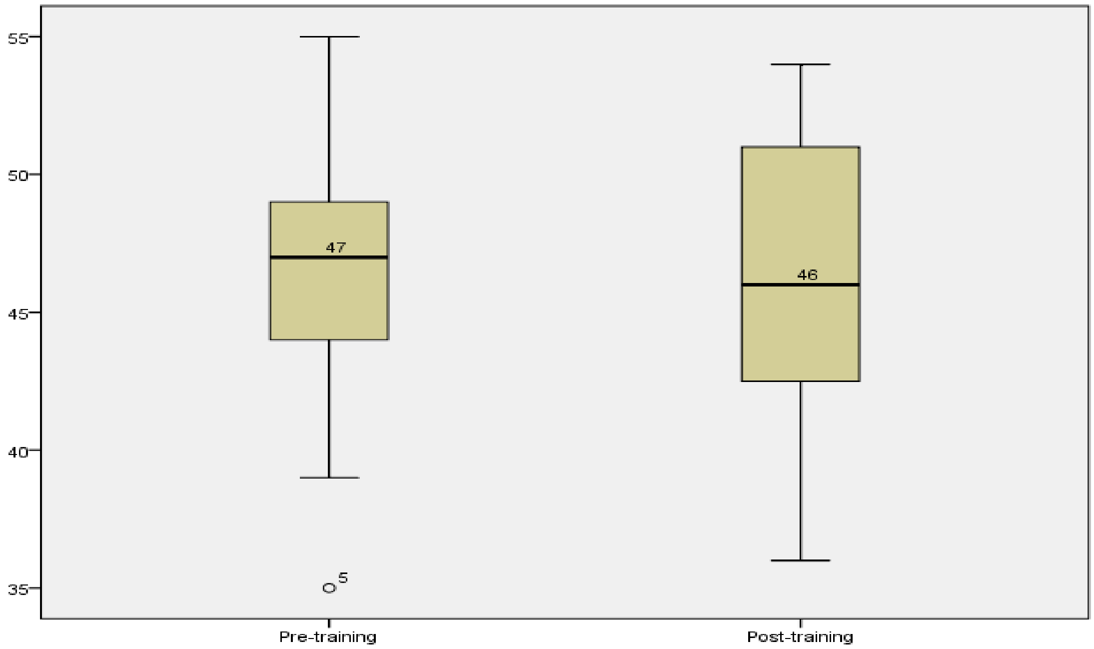


Figure 7.5: Comparison of the PBS scores pre-and post-training

Table 7.2: Paired t-test for PBS [Pre- and Post-training]

ID	Pre-training	Post-training	Difference
1	45	41	-4
2	50	x	x
3	49	54 *	5
4	49	53 *	4
5	35	36 *	1
6	53	49	-4
7	48	46	-2
8	44	45 *	1
9	55	54	-1
10	47	46	-1
11	39	38	-1
12	44	44	0
Mean	46.18	46	-0.18
SD	5.76	6.16	2.86
95% CI of difference			**(-1.74)-2.1**
P			**0.84**

SD= standard deviation, CI= confidence interval, P= significant value of ≤0.05

*** An increase in the PBS total score at post-training shows improvement**

7.5.3 TUG

The data from TUG has shown to be normally distributed, therefore, paired t-test and a box plot was used to analyse the difference between pre- and post-training (Table 7.3 and Figure 7.6). The mean difference between pre- and post-training of TUG was 0.73±2.45 with a 95% CI [-0.92-2.38], which was not statistically significant [p=0.35]. There was a decrease in the TUG post training in seven participants [ID; 1,5,6,7,9,10,11], however only two exceeded the MCID threshold of 1.7, 1.2, 1.9 seconds for children with CP at GMFCS levels I, II and III respectively (Hassani et al. 2014).

Table 7.3: Paired t-test for TUG [Pre- and Post-training]

ID	Pre-training	Post-training	Difference
1	12	8 *	4
2	8	x	x
3	7	7	0
4	9	9	0
5	8	7 *	1
6	8	7 *	1
7	9	8 *	1
8	8	12	-4
9	9	8 *	1
10	13	12 *	1
11	18	13 *	5
12	13	15	-2
Mean	10.36	9.64	0.73
SD	3.3	2.84	2.45
95% CI of differences			**(-0.92)-2.38**
P			**0.35**

SD= standard deviation, CI= confidence interval, P= significant value of ≤0.05

*** A decrease in the timing of TUG at post-training shows improvement**

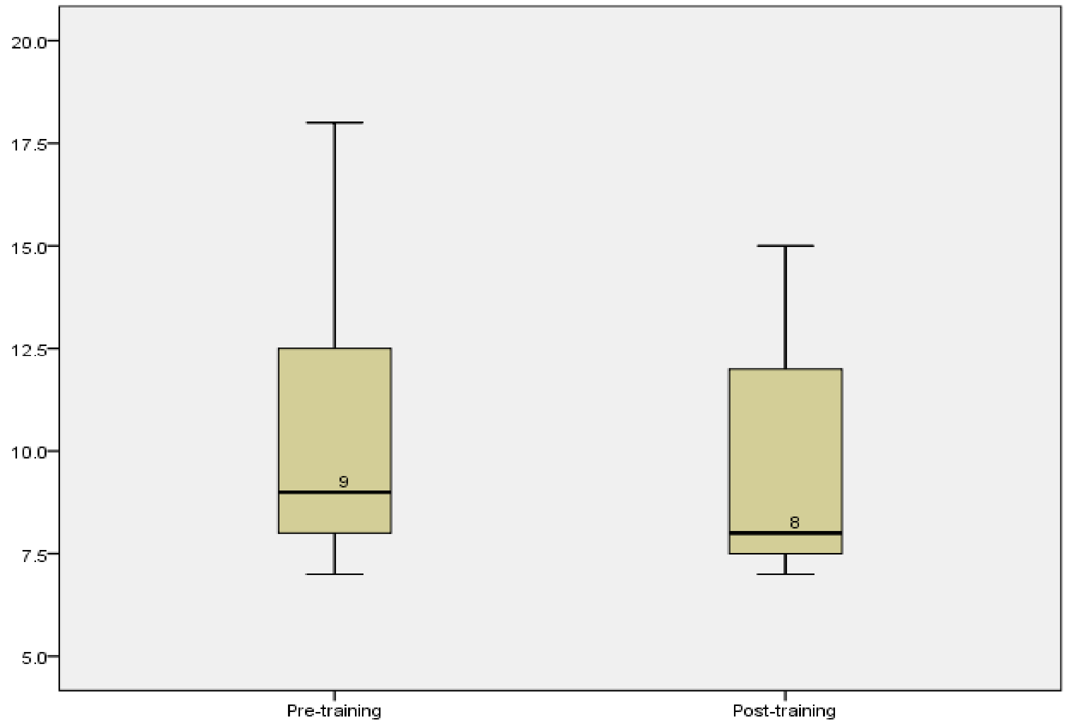


Figure 7.6: Comparison of the TUG score pre-and post-training

7.5.4 Results of secondary outcome measures

7.5.4.1 Adherence

The number of sessions attended by each child was recorded in their respective attendance sheets (Appendix 32). Two children only chose to attend {three sessions per week} a total of 12 Wii Fit sessions. One of them has attended all sessions with 100% adherence while the other has attended nine sessions of 12 with 75% adherence. On the other hand, the majority of the sample, nine children, chose to attend {two sessions per week} a total of eight sessions during four weeks. Six children have attended all eight sessions with 100% adherence, while two children has attended seven sessions with 87.5% adherence and only one child has attended six sessions only with 75% adherence. In general the percentage of attendance was not less than 75% and the majority of children showed 100% adherence to Wii Fit sessions, indicating a high level of motivation. In addition, the number of times each game has been played during each session was recorded for each child (Table 7.4 and Graph 7.1). Between the four main selected games, the 'Table Tilt' was the most played game by all children with a total of 289 times. Though, the 'Soccer Heading' was the least played game by all children with a total of 170 times, as six children did not prefer to play this game. Furthermore, as children were given the option of playing optional two games, it can be seen that children chose to play with 'Tightrope Walk' game [138 times] than 'Balance Bubble' game [93 times]. This variation in preference might be due to the visual characteristics of each game from colours, number of items displayed, and the main character feedback.

Graph 7.1: The number of times each game was played

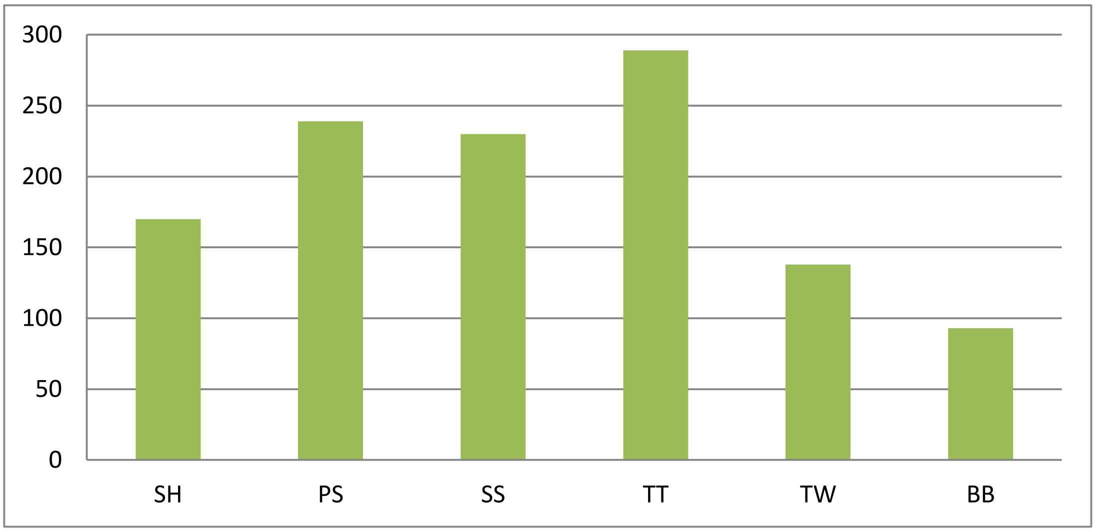


Table 7.4: The number of times each game was played by each child

	The main selected games				The optional games	
ID	**Soccer Heading**	**Penguin Slide**	**Ski Slalom**	**Table Tilt**	**Tightrope Walk**	**Balance Bubble**
1	35	35	35	32	10	3
2	12	13	10	12	2	0
3	24	24	24	24	4	2
4	24	24	24	24	2	7
5	0	19	0	25	16	10
6	16	17	40	23	0	21
7	10	15	15	20	12	0
8	3	21	16	28	25	18
9	5	18	3	24	21	18
10	18	5	12	26	24	14
11	11	20	24	24	18	0
12	12	28	27	27	4	0
Total	**170**	**239**	**230**	**289**	**138**	**93**

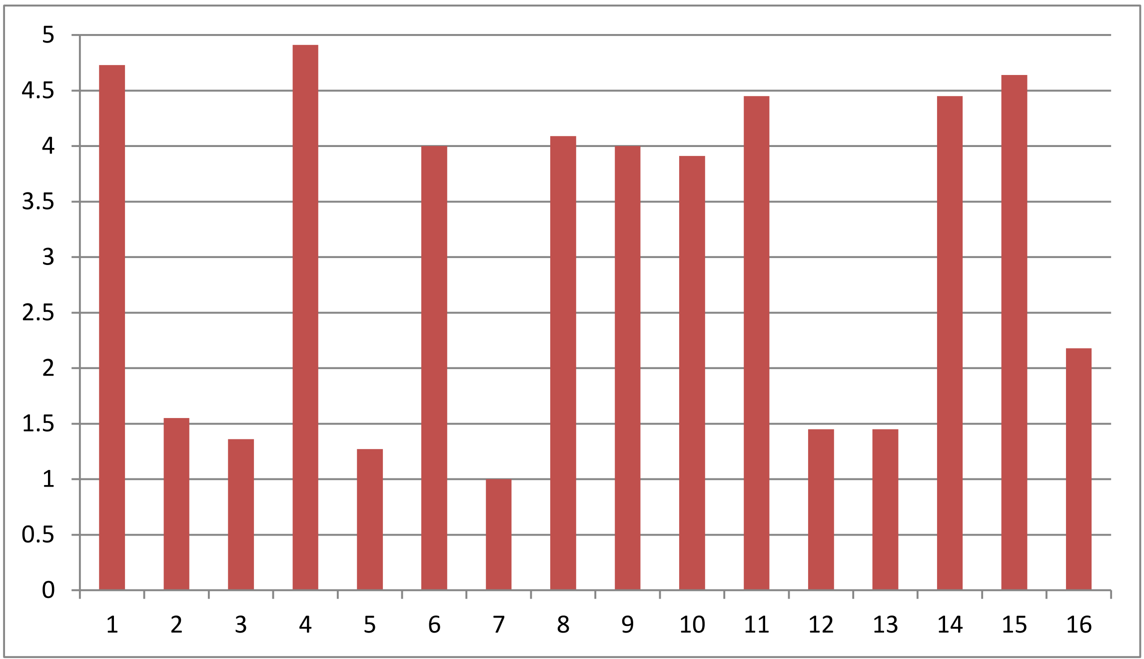
7.5.4.2 Enjoyment

The PACES was used to identify the level of enjoyment experienced by children with CP while playing the Wii-fit balance games (Appendix 36). It comprises16 items and a 5-point Likert-type scale {1 = 'Disagree a lot' to 5 = 'Agree a lot'}. A score was calculated by averaging the scores of all the children for each individual item (**Graph 7.2**).

It was observed that items numbered; 1, 4, 6, 8, 9, 10, 11, 14 and 15 have shown high rating of above 3.5/5 across children. These items were positive statements of enjoyment which were; "I enjoy it", "I find it pleasurable", "It gives me energy", "It's very pleasant", "My body feels good", "I get something out of it", "It's very exciting", "It gives me a strong feeling of success", and "It feels good" respectively. The highest rating was 4.9/5 in item 4 which include the statement "I find it pleasurable".

The items numbered; 2, 3, 5, 7, 12, 13 and 16 have shown low rating of less than 2.5/5 across children. These items were negative statements of enjoyment which were; "I feel bored", "I dislike it", "It's no fun at all", "It makes me sad", "It frustrates me", "It's not at all interesting" and "I feel as though I would rather be doing something else". The lowest rating was 1/5 in item 7 which include the statement "It makes me sad". This means that all children with CP agreed that playing Wii Fit balance games were enjoyable.

Graph 7.2: The average score for each item of PACES



7.6 Discussion

The main aim of this study is to test the methodological feasibility for conducting a future RCT that will investigate the effect of the Wii Fit balance games on the balance of children with CP. In addition, this study investigated the preliminary effect of the Wii Fit balance games on standing stability by using the COP length from the WBB and on functional balance mobility by using the PBS and TUG for children with CP. The main results showed no significant differences in either the static balance through the COP length or the dynamic balance through PBS and TUG between before and after the Wii Fit balance games training. The lack of significance was expected due to the small sample size and the short training duration. Although the aim was to train children with CP using 12 sessions, the majority of children chose to attend eight sessions only. This shows that attending two sessions is more feasible and convenient; however the duration of four weeks was not enough.

The results of this study are consistent with the results of Ramstrand and Lygnegard (2012), which showed no significant difference in the COP velocity measured by an force plate following Wii Fit balance games. The sample size and the children's functional level were similar to those in this study; however, the number of sessions was 25 and the setting was at home. In contrast, three other studies (Sharan et al. 2012; Jelsma et al. 2013; Tarakci et al. 2013) were not in agreement with the results of this study. These studies stated that children with CP showed significant improvements in different functional dynamic balance measures.

The TUG was a common outcome measure between this study and the study by Tarakci et al. (2013); however, children in the Tarakci et al. (2013) study were trained with Wii Fit balance games for 24 sessions, whereas children in this study were only trained for eight sessions. The PBS was also a common outcome measure between this study and the Sharan et al. (2012) study; however, the games played in the Sharan et al. (2012) study were a mix of Wii Fit and Wii Sports games, whereas in this study only Wii Fit balance games were played. In addition, children in this study were identified by their functional level of GMFCS, unlike the sample of children in the Sharan et al. (2012) study, which was post-operative without any details about the children's gross motor functional level. Furthermore, there were only eight children with CP who were trained with Wii for nine sessions only and who showed significant improvement in PBS after training in comparison to the control group. However, the testing of between group significant differences was not reported properly, and the sample size was too small to reach a conclusion. On the other hand, this study included 11 children with CP who were trained for eight sessions and who did not show a PBS improvement.

Jelsma et al. (2013) used different outcome measures than this study; however, they found a significant medium improvement effect in balance scores only after the Wii Fit training phase. The sample included 14 children with hemiplegic CP with GMFCS levels I and II and a mean age of 11.4 ± 1.8 years. However, this study sample included 11 children with CP {hemiplegic and diaplegic} with GMFCS levels I, II, III and a mean age of 8.7 ± 2.2 years. In addition, there were 12 Wii Fit training sessions in three weeks, in contrast to this study in which there were eight sessions in four weeks. This shows that intense regular training in a short period of time can result in a short-term effect. However, regular daily training might not be practical in clinical settings.

Regardless of significance, this study is a feasibility study, and individual findings for each participant are more valuable. The individual results showed improvements in one or more of the outcome measures by each participant, and some reached the MCID. The majority of participants, seven out of eleven, showed improvement in the TUG while only two exceeded the MCID threshold. This agrees with the previous studies presented in literature, which found significant improvements in TUG after Wii Fit training for older adults (Laver et al. 2012; Rendon et al. 2012; Singh et al. 2013), stroke patients (Cho et al. 2012; Barcala et al. 2013; Hung et al. 2014; Morone et al. 2014; Yatar & Yildirim 2015), adults with PD (Zettergren et al. 2011; Esculier et al. 2012), children with TBI (Tatla et al. 2014) children with developmental delay (Salem et al. 2012), and children with CP (Tarakci et al. 2013).

There has been an improvements in the PBS presented in four participants, where the highest improvement was an increase in the PBS score by five points. However, it did not reach the MCID of 5.8. The PBS is a modified version of the BBS; improvements in the BBS in the previous research confirm the individual improvements seen in the PBS in this study. There was a significant improvement in the BBS after Wii Fit training for older adults (Williams et al. 2010; Williams et al. 2011; Bateni 2012; Laver et al. 2012; Padala et al. 2012; Chao et al. 2013), stroke patients (Cho et al. 2012; Barcala et al. 2013; Hung et al. 2014; Morone et al. 2014; Yatar & Yildirim 2015), adults with PD (Zettergren et al. 2011; Loureiro et al. 2012; Pompeu et al. 2012; Mhatre et al. 2013), adults with TBI (Cuthbert et al. 2014) and children with CP (Sharan et al. 2012).

The COP length calculated from the WBB data, which was collected from children with CP before and after training, did not show any significant differences. In general, there was an increase in the COP length after Wii Fit training. However, there was a decrease in the COP length post-training in five participants during eyes open. Although the differences was not significant, it agrees with previous studies that showed decreases in the COP sway area following Wii Fit training for older adults (Cho et al. 2014), adults after knee surgery (Sims et al. 2013), stroke patients (Cho et al. 2012; Barcala et al. 2013) and children with lower limb amputations (Andrysek et al. 2012).

The individual improvements seen in the outcome measures are not significant and are not considered as the main findings of this study. However, these findings highlight the potential effect of the Wii Fit balance games on standing stability and functional balance mobility, which can be investigated further with a larger sample size. The feasibility aspects of using Wii fit games in clinical and research settings for children with CP was also considered. These aspects were mainly related to the feedback from children with CP about their enjoyment in the games, their adherence rate and their preference to some Wii fit gams over the other. The results of this study showed high adherence rate of 75% to 100%

percentage of attendance to Wii fit sessions, which indicates a high level of motivation. The enjoyment level was assessed with participants' rating of the PACES. The results showed high rating of above 3.5/5 across participants in nine positive statements of enjoyment. In addition, children's preference to some games over the other is not just an individual preference but it highlights aspects of the game that might affect the suitability of these games to children with CP. Furthermore, the scoring system of the games are based on timing where some children could not react fast to the game and end up having a low score. Although scores are not considered in this study, children are highly affected by these scores. Wii Fit games will be further discussed in Chapter 8 with recommendations to games that can be used for children with CP.

7.7 Conclusion

The Wii Fit balance games are enjoyable games to be used in rehabilitation by children with CP. The present study found that Wii Fit balance games, when played for twice a week for 4 weeks, may not affect their standing postural control or functional balance level significantly. This was due to the small sample size to find a significant effect. However further research with larger sample is needed to confirm this conclusion. Though, the main aim of this study is to investigate the methodological feasibility for conducting future RCT. Therefore, further feasibility aspects including recruitment rate, duration of training, research settings, selection of outcome measures, and which games are more suitable for children with CP and assure the therapeutic purpose, all are discussed further in Chapter 8.

Chapter 8: Discussion and conclusions

This chapter includes an overall discussion of the research findings with respect to the feasibility aspects of using the WBB as an assessment tool and using Wii Fit games as an intervention tool for children with CP, either in clinical practice or future studies. Then a list of recommendations for a future RCT is provided. The limitations of this research are highlighted, and the final general conclusions are listed.

8.1 General discussion

The main purpose of the present research is to investigate the usability and potential effect of commercially available technology, the Wii Fit games, as a postural control training tool and of the WBB as a postural control assessment tool in clinical rehabilitation for children with CP. This research study comprised three stages (Figure 1.1). The first stage was an experimental study to select the appropriate software to communicate with the WBB (Chapter 4). This stage showed that MATLAB® gave more rigorous data than Stance©, due to several errors in calibration and programming. However, the results from this stage generated useful insights that were not evident in existing literature. For example, the minimum weight that the WBB can measure accurately is 10 kg, which is an important consideration when assessing children. Furthermore, the measurements of two WBBs are different unless they are calibrated in the same way.

The second stage comprised two studies to investigate the reliability with respect to within- and between-session COP length data provided by the WBB among children with and without CP. Data from the first study (Chapter 5), collected from 12 children, found that among school-age children, the double-leg stance on the WBB provided more rigorous reliability values than the single-leg stance. This finding is in agreement with Park and Lee (2014), who showed that double-leg stance tasks have stronger correlation reliability values than single-leg stance tasks. In addition, Larsen and colleagues (2014) found larger variations in single-leg stance tests, indicating intra-subject variability and a high level of difficulty for children.

The second study (Chapter 6) investigated the reliability of the WBB when assessing COP path length in children with CP. Because children with CP may behave differently while standing and may thus provide different reliability values. However, the single-leg stance was not tested in children with CP due to the difficulty of the task and the variable results found in Chapter 5. The results of the second study showed that among children with CP, the double-leg stance with eyes open provides more rigorous reliability values than with eyes closed. These results were in agreement with the first study's results (Chapter 5), which reject the H_0 hypothesis and accept the H_1 hypothesis of "The WBB will provide a reliable COP length measure of staning balance among children with or without CP" during the double-leg stance with eyes open.

These findings may be due to the steadiness of the task involved, as balance can easily be maintained in the double-leg stance with eyes open.In addition, children with CP rely on their visual sensation to compensate for the lack of proprioception sensation (Wingert et al. 2009) to maintain balance during standing, which means that without visual sensation, standing with eyes closed is a challenging task to perform. It was unclear whether this was because of the child's lack of balance and difficulty when performing tasks or because of the limited technology of the WBB to capture COP with higher levels of sway. However, the variability in COP length calculated from the WBB data was highly correlated with the COP length variability calculated from the force plate during the single-leg standing task (Huurnink et al. 2013). Therefore, the variable data during the single-leg stance was caused by intra-subject variability, while the WBB quantified the COP trajectory accurately. Nevertheless, the reliability of the WBB measurement was acceptable with a small sample size; thus, further studies with larger samples are recommended, especially for double stance with eyes closed for children with CP and single stance for TD children.

The third stage was a methodological feasibility study, to determine the possibility of conducting an RCT with a larger sample to confirm the effectiveness of Wii Fit games on children with CP (Chapter 7). The results of this study showed no significant differences in the COP length of the static balance or the PBS and TUG of the dynamic balance between before and after the Wii Fit balance games training. This result accept the null hypothesis "H_0: children with CP will show no balance improvments highlighted in a decrease in the COP length during double stance, increase in the total score of the PBS, and deacrease in the time to complete the TUG following four weeks of the Wii Fit balance games training intervention". However, this was because of the small sample size and the short training period of four weeks.

While these results were consistent with Ramstrand and Lygnegard's (2012) results, which showed no significant difference in the COP velocity following Wii Fit balance games, they failed to agree with the results of other studies (Sharan et al. 2012; Jelsma et al. 2013; Tarakci et al. 2013), which stated that children with CP showed significant improvements in different functional dynamic balance measures. Regardless of the lack of significance, individual findings from each participant showed improvements; seven participants decreased the TUG, two participants exceeded the MCID of 1.9 sec, four participants increased the PBS but did not reach the MCID of 5.8 and five participants decreased the COP length.

These individual improvements agree with previous studies, which showed improvements in the same outcome measures following Wii Fit training. Although these improvements were not significant, they highlighted the potential effect of the Wii Fit balance games. In this study, children with CP were at GMFCS levels I-III, meaning they were able to stand independently on the WBB to play the Wii Fit games. The difference between the levels refers to how long they can stand without support. For example, children at level III require some support while walking, which means some might also need support when standing for long periods, unlike children at levels I-II who are able to stand and walk independently. In this case, children of different levels may show different levels of improvement, and thus, taking the average improvement in the group might not represent the significant improvement of the minority at level III. In addition, children at level I possess the highest level of functioning, which makes significant improvements hard to find in a short training period.

8.1.1 The feasibility of using WBB balance assessment tool in research and clinical settings

Clinicians may benefit from using the WBB to bridge the gap between laboratory quantitative objective measures of standing and the subjective rating measures of functional movement. However, several feasibility points need to be considered before recommending the WBB for clinical use, as researchers agree that WBB cannot replace the gold standard laboratory force platforms. This is because force plates have been specifically designed to assess balance with various parameters and they use specific communicating software. By contrast, the WBB is designed for the purpose of playing games by communicating with the Wii console.

Using the WBB as a balance assessment tool is not a straightforward procedure. In order to use the data from the WBB's sensors, the WBB needs to communicate with a computer using appropriate software. This software needs to access the WBB sensors through Bluetooth and the open source library [WiimoteLib]. Subsequently, a calibration protocol (Appendix 1) is required to reset the calibration factors of each sensor before extracting data from the WBB's sensors at a chosen frequency and duration. Moreover, the software should be programmed with a list of mathematical calculations to calculate the resultant COP coordinates from the extracted data. Then the COP parameters such as mean velocity or COP length, which include distance and time, can be calculated. In this manner, quantitative COP parameters can be used to assess standing balance.

Therefore, to use the WBB in a clinical setting, specific programmed software must be designed and connected to the WBB via Bluetooth. Clark and colleagues (2010) were the first to test the reliability and validity of the WBB as a measure for COP parameters using custom designed software [LabVIEW 8.5] and a calibration protocol (Appendix 1); other researchers have followed this protocol using a variety of software. However, much of the software used was neither user friendly nor easy to apply and understand. The process of obtaining information from the WBB requires people with experience in software coding, which could be inconvenient for clinicians. However, user-friendly software can be designed and programmed to connect with the WBB through a proper calibration process for clinical usage. Park and Lee (2014) designed user-friendly software called “Balancia” for use by clinicians and showed the validity and reliability of the data obtained from the WBB. However, until this software becomes commercially available, the WBB may not be feasible for clinical use.

To calibrate the WBB, data are first collected from the sensors when no weight is applied, and then when a standardised weight is applied. The location of the applied weight also needs to be made known to the software programme to calculate the calibration factors. The developmental work to assess the software (Chapter 4) found calibration errors with Stance© because it was unable to measure the weight. As poor calibration will lead to errors and poor outcomes, the calibration process is mandatory when working with force platforms and the WBB. However, while force platforms, especially those belted to the floor, only need to be calibrated occasionally, the WBB needs to be calibrated every time it has been moved, due to its portability. This means that when using the WBB in clinics, frequent calibration with a known weight is necessary.

Existing research has shown that the WBB is feasible for use as a balance assessment tool in research. However, few feasibility considerations were highlighted for future researchers. Such feasibility aspects to consider include the time taken to set up the connection between WBB and the software, the calibration process, the equipment required such as a certified weight of 5 kg, a Bluetooth dongle and a laptop installed with the custom software. In addition, Bluetooth disconnection or connection disturbances cuased by other Bluetooth devices are possible problems that could affect the data transfer between the WBB and the laptop, thus leading to errors in recordings. This study used the COP length as the main outcome measure collected from the WBB, whereas previous studies calculated different COP parameters. Although the different outcomes highlight the flexibility of the WBB’s data for different calculations according to the research purpose, these outcomes are still primitive and unsophisticated, unlike those of force plates. Nevertheless, the portability of the WBB makes it favourable for conducting research in different settings, and it is a cost effective tool for researchers with limited funds.

In summary, as a game tool, the WBB was not designed for clinical use. However, its technology has proved to be a feasible, reliable and valid tool for use in balance assessment. This research showed the reliability of the WBB data, when assessing balance for children with and without CP, and showed the feasibility of using the WBB as a balance assessment tool for children with CP in clinical settings.

8.1.2 The feasibility outcomes for conducting future RCT to test the effect of Wii Fit games as balance intervention tool on children with CP

The main aim of the feasibility study is to answer the question, “How feasible is it to conduct an RCT study on the effectiveness of Wii Fit games on balance for children with CP?” The outcomes of this study are to provide information about the recruitment process and to estimate the recruitment rate, the delivery of intervention including the convenient research settings and duration of training, the selection of outcome measures, the adherence rate and enjoyment level, and the suitability of the games for children with CP. Each outcome is discussed separately, accompanied by a list of recommendations for future studies.

8.1.2.1 Recruitment process

One of the major challenges of this study was the recruitment process of children with CP. IT took about a year to recruit six children with CP from three sites in Southampton, UK (Figure 6.1) and a further three months to recruit six children with CP in Riyadh, Saudi Arabia. The differences in recruitment periods may be caused by the prevalence rate of CP, the limited inclusion criteria such as age and functional level and the sites from which children with CP were recruited.

The prevalence rate of CP among children around the world is about 2.11 per 1,000 live births with a 95% confidence interval range of 1.98–2.25 (Oskoui et al. 2013). In the UK, the prevalence of children born with CP is about 2.5 per 1,000 births (Blair & Stanley 1997), whereas the prevalence rate of CP among children born in Saudi Arabia is about 4.1 per 1,000 live births (Al-Asmari et al. 2006). These differences explain the different recruitment rates between the UK and Saudi Arabia. These country rates decrease more when considering a specific city such as Southampton.

The main inclusion criteria are children with CP aged 6–12 years old at GMFCS levels I-III. Children with these criteria in the UK attend mainstream schools, which narrowed the possibilities of screening for them through public charities and networks for children with special needs within the Southampton area. Nevertheless, about eight children were eligible for recruitment, of whom six were included. The Solent NHS community services were also approached to help identify children with CP within Southampton. Although invitations were sent through the Solent NHS, no replies were received. However, the research coordinator from the Solent NHS community services reported that according to their records, only 20 children with CP met the inclusion criteria in Southampton. As it took about a year to screen for and recruit six children with CP from Southampton, UK, the estimated recruitment rate is 30% from the city of Southampton.

By contrast, most children with CP in Saudi Arabia attend special schools and only a limited number attend mainstream schools. In addition, the health care system in Saudi Arabia does not provide community physiotherapy services, and children with CP are treated at public physiotherapy clinics, special schools or private clinics. Therefore, screening for children with CP took only three months through one physiotherapy clinic in Riyadh. Eleven children with CP were identified as eligible for the study, of whom six were included. Therefore, the estimated recruitment rate is 54.5% from one physiotherapy clinic in Riyadh, Saudi Arabia.

To conduct a similar study in the UK in future, setting up a multi-centred RCT with a Wii Fit training station in each city is recommended to obtain a larger sample, as the recruitment rate is expected to be low. However, this may not be feasible and will require a higher budget. Conversely, when conducting a similar study in Riyadh, Saudi Arabia, the recruitment rate is higher; however, it is recommended to recruit from more than one physiotherapy clinic or from special schools, where children with CP can be easily identified, to speed up the process of recruitment and to negate the need for a multi-centred RCT.

8.1.2.2 Research settings

The portability and availability of Wii Fit games makes it feasible to use this tool in various settings such as at home or school, or in a clinic or laboratory. However, the effect of each setting on the research results needs to be considered. For example, conducting a study of the Wii Fit training as home therapy will reveal the long-term effects of the Wii Fit training on maintaining the functional level and the feasibility of its use as home-based exercise. However, because of the lack of supervision, the children could easily cheat on the games and they may not perform the right movements for therapeutic purposes while focusing on winning. By contrast, school and clinical settings ensure greater supervision and control over the child’s performance while playing the games. In addition, these settings are convenient for children because they can have Wii Fit training sessions within a physical activity class at school or as part of their rehabilitation session at a clinic. In this case, the children and their families are likely to exhibit greater adherence to the training programme regardless of its duration.

The laboratory setting in the present study was less convenient and feasible for conducting a study for children than were other settings, because the children were required to travel to the laboratory after school, which placed a burden on the participants' families {parents and siblings}, especially when they were involved in extra-curricular activities. While school and clinical settings place less of a burden on the parents in terms of travel time and arrangements, and the child is familiar with the locations, there may be space limitations in school settings or time limitations in clinical settings. This study did not examine the feasibility of the different settings and their effects on balance outcomes; however, future studies should consider this point.

Regardless of the laboratory setting in the present study, the adherence rate of the sample ranged from 75% to 100%. However, the training programme only lasted for four weeks; thus, a longer training period could have affected the children's adherence. In addition, the majority of participants attended training twice a week instead of three times, thus confirming the lack of convenience of the laboratory settings. Therefore, laboratory settings are less feasible for future RCTs than school or clinical settings. If future RCTs are conducted in Riyadh, Saudi Arabia, special schools can be approached for the recruitment and data collection.

8.1.2.3 Duration of training

The present study chose a training intensity of 30 min, two times a week for four weeks. The findings from the present study indicate that eight sessions were insufficient for observing improvements in balance, especially for highly functioning children with CP, and that a longer duration of training may have shown some improvements. This short duration of training was selected due to the limited published studies at the time this study was conducted, thus making it impossible to follow the recommended duration of training for children presented in the literature, which was three 30 min sessions per week for a period of six to eight weeks (Abdel-Rahman 2010; Andrysek et al. 2012; Ferguson et al. 2013; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014; Tatla et al. 2014).

However, the initial selected duration of training in this study, which equated to 12 sessions, was similar to the minimum duration used in the literature to show the effect of Wii Fit games training (Abdel-Rahman 2010; Jelsma et al. 2013; Hammond et al. 2014). For this feasibility study, the participants were given the option of attending training sessions either two times or three times a week. The majority of the participants chose to attend twice a week for four weeks for a total of eight sessions.Although this duration of training was feasible, it was lower than the intensity recommended in the literature to show the effect of training with Wii Fit games.

To prevent the children from experiencing boredom and fatigue, sessions should not be held more than three times a week. The training period should be balanced between six and eight weeks to maintain the participants' adherence and enjoyment levels. This means that between 12 and 24 sessions of Wii Fit games training might be sufficient for showing balance improvements in children with CP. If it seems impracticable to assess a long training period in future studies, a more convenient research setting, at schools or clinics, could improve adherence to the training.

8.1.2.4 Outcome measures

The three main outcome measures used to show the effect of Wii Fit games on balance were the COP length measured using the WBB for static standing balance and the PBS and the TUG for dynamic functional balance. Previous studies conducted with adults or children with limited balance have shown improvements in the TUG and BBS, which is similar to PBS. Each measure will be discussed in relation to whether it was a feasible measure to be used in research, and whether it was the appropriate measure to show the effect of the Wii Fit games for this sample of children with CP.

The COP length is an outcome of standing static stability. The results of this study showed no significant decrease in the COP length, which might have been because this selected outcome measure could not reflect the dynamic effect of the game. In addition, other COP parameters such as COP velocity, maximum sway in AP or ML directions and COP sway area were not used. These parameters might have allowed a better assessment of standing COP trajectory and led to a better judgment on the effect of the games on postural control. However, these laboratory parameters would have been assessed rigorously through laboratory force plates.

As an outcome of standing postural control, WBA could also be used; this might be a better measure of the effect of Wii Fit games than COP parameters, because of the multidirectional weight shifting required during playing the Wii Fit games. Therefore, when children with CP are playing these games, their weight shifting ability tends to improve more than their static stability while standing. In this sense, an improvement of symmetrical weight bearing while standing and walking, especially for children with hemiplegic CP, can be seen as a positive effect of Wii Fit games, whereas a decrease in the COP length during static standing may not be seen. Additionally, the results of the COP length per sec slightly increased after training, thus supporting the argument that games encourage dynamic balance control rather than static stability. Therefore, it might be more practical to measure the outcome of WBA when assessing the effect of Wii Fit games in future studies, which can be measured using the WBB (Clark et al. 2011; Clark et al. 2014). Future studies therefore have the flexibility to measure WBA with a laboratory force plate or with the WBB.

The PBS and TUG were used in the present study to assess dynamic functional balance. These measures are usually used by physiotherapists in clinics to track the progression of the child's improvement. These measures are feasible and convenient for children and physiotherapists, as they are time-saving to use in clinical settings. The PBS and TUG were considered feasible measures to use in the present study. However, the results of this study showed no overall significant improvement in the PBS or TUG after four weeks of Wii Fit training. The lack of significant changes is due to the small sample size and the short period of training. A larger sample size and longer training period could result in significant changes in the TUG and PBS.

Nevertheless, individual findings from each child showed a decrease in the TUG for seven children, two of which were clinically significant, and an increase of PBS in four children, but they did not reach the MCID. Although the Wii Fit games rely mainly on weight shifting, they score the player’s performance according to the player’s speed. This may have influenced the children’s performance in the TUG and PBS, because most of the games rely on how quickly the child can perform the task. For example, the TUG measures how quickly you walk without falling. In addition, the PBS items like sitting, standing, picking up an object from the floor, turning, stepping and reaching are mostly assessed according to the time taken to complete the task.

The results of PBS presented in the study were based on blinded assessors who rated the children’s performance through video recordings. This method was used to avoid researcher bias. However, on-site rating is different to video rating, as video clips might lack clarity or have a poor recording angle, making it difficult for the assessor to assign proper ratings. To test the reliability agreement of the rates, the researcher’s rating of PBS were compared with the blinded assessor’s rating (Appendix 37). However, this was not a feasible process, and the blinded assessor should be located on site to rate PBS in the future RCT.

8.1.2.5 Adherence, safety and enjoyment rate

Children with CP usually lack interest in therapy at a certain point in their rehabilitation, especially when their condition plateaus and improvement is no longer evident (Hanna et al. 2009). Introducing a new intervention tool to the rehabilitation programme that involves virtual reality video games such as the Wii Fit games will possibly break the cycle of boredom from regular exercises and increase motivation. Therefore, this study measured adherence and enjoyment level to explore the impact of Wii Fit games on motivation for training and exercise in children with CP.

Adherence was measured by the percentage of sessions attended; however, the results were affected by limitations of time and transport. As the present study required the children to attend training sessions at a research laboratory, parents had to make the necessary arrangements to bring their children to the laboratory after school. Commitments to extracurricular after school activities sometimes made it difficult for the children to commit to the programme. Nevertheless, the results of this study showed a 75%–100% adherence rate, which indicates a high level of motivation, which could be linked to the enjoyment level the children experienced while playing the Wii Fit games.

The PACES showed a high rating of above 3.5 out of 5 for positive statements of enjoyment. The participants found the games encouraged functional movements and exercise in a highly interactive and enjoyable way. This was represented by the high ratings for statements such as, “I enjoy it”, “I find it pleasurable” and “It’s very pleasant”. Other views were that the games stimulated sensory input of vision, auditory, and proprioception, which increased the child’s participation in the game. This was represented by the high rating for statements such as, “My body feels good” and “It gives me energy”. The participants also reported a sense of achievement, which was reflected in the high scores for statements such as, “I get something out of it”, “It gives me a strong feeling of success” and “It feels good”. Children with CP often lack motivation towards conventional rehabilitation training, especially when their functional levels have plateaued. However, the Wii Fit games are a new modality that the children consider as fun games rather than training tools; this might be another reason for the high enjoyment level.

8.1.2.6 Suitability of the games for children with CP

The Wii Fit balance games were designed to be played by the healthy population; therefore, several points need to be considered when using these games for rehabilitation. The scoring systems of the games mostly rely on the time taken to complete a task and the number of items collected during the game, which is not a good indicator of the child’s functional improvement and cannot be used for assessment. For assessment purposes, how the child moves to play the game is more important than the score. Therefore, physiotherapists may need to attend the gaming sessions to direct the child to perform the required therapeutic movement. However, children are highly driven by the total score, which may be equally important for motivating the children and improving their participation.

At the end of each game, the player was rated against other players, which was intimidating for some of the children. Furthermore, some games provided negative feedback in the form of characters crying or showing a disappointed face when lower scores were recorded. These aspects had a negative effect on the child’s motivation to continue training which would not occur in conventional physiotherapy rehabilitation sessions, where the child would be motivated by the therapist.

The visual graphics, colours and additional characters of the games had a visible effect on the children's concentration levels, a fact which needs to be considered when selecting the most suitable games to use for training. Games such as Soccer Heading where balls, pandas and shoes are thrown at the player by other characters were distractive and affected some players' ability to identify appropriate ways to achieve maximum scores. Most of the children preferred the games with minimal distractions, and six participants refused to play Soccer Heading. By contrast, the Table Tilt game was the most played game due to its simplicity and use of fewer graphics in the game {colourful balls on a table} and the absence of a crying character for lower scores at the end of the game.

To ascertain which Wii Fit balance games are most recommended for balance rehabilitation of children with CP, each game will be discussed separately based on the participants' feedback and the postural requirements when playing the games.

1- Soccer Heading

The aim of this game is to hit the footballs and avoid other objects such as shoes or panda heads. The game is scored according to the number of balls the player hits minus the number of pandas or shoes that were not avoided. As stated above, this game was distractive for the children and thus affected their ability to make decisions about the appropriate weight shifting direction by which to achieve maximum scores. Six children refused to play this game because they felt that it was difficult to play or that it was scary having balls and other objects thrown at them.

The children with CP who agreed to play the game showed lower muscular strength than the TD children at the hip, knee and ankle extensors, which led to primarily use of trunk for the ML sway (Ballaz et al. 2014). This was also observed in children with CP in this study despite the physiotherapists encouraging the use of the lower limbs to play rather than the adapted trunk movement. Michalski et al. (2012) found that while playing Soccer Heading, young adults displayed an increase in the ML-COP sway, a decrease in shoulder rotation and tilt and no reduction in pelvic rotation and tilt (Michalski et al. 2012). This means that the weight shifting practice while playing this game mainly involves trunk movement because while the player's attention is drawn to focus on the balls being thrown they forget to use their lower limbs. As a result, children with CP may not improve their postural control by playing this game. Additionally, this game forces players to react quickly, which may not be suitable for children with CP, as this will increase their levels of spasticity and may cause injuries.

2- Ski Slalom

In this game, the player is required to move from side to side to make the skier ski between two flags that are located alternately on each side of the slope. The players score a point, based on their speed, each time they pass between the two flags. This game provides visual feedback in the form of a red dot, which represents the COP movement, on a simple diagram of the WBB on the top right of the screen. There is a blue area in the front half of the WBB diagram toward which the player needs to move the red dot by leaning forward. Moving the red dot to the blue area increases the player's speed.

This game requires the player to retain his or her balance while leaning forward and weight shifting from side to side. However, children with CP have a decreased ROM of their hips, knee extension and ankle dorsiflexion (Lowes et al. 2004), which makes them adopt a crouched posture (Burtner et al. 1998). This posture places their COG anteriorly, because of the lack of balance between the ankle plantar flexors and dorsiflexors to control the body's COG, and their COP will move posteriorly (Winter 1995). As this game asks the players to move their COP anteriorly, they are likely to lose their balance. Therefore, children with CP in this study were instructed not to move forward, as the total score is not as important as their ability to shift their weight to pass between the flags. However, the children were affected by the negative feedback at the end of the game when the character cried because of the low score, and thus three out of the eleven children with CP in this study preferred not to play this game.

Michalski et al. (2012) analysed the postural changes in young adults while playing the Wii Fit games. Young adults showed decreased ML-COP sway, shoulder rotation, shoulder tilt, pelvic rotation and pelvic tilt while playing the Ski Slalom game. Greater coupling of the upper trunk and pelvic movement was evident, indicating a higher focus on the lower limb movement. This game contains feedforward strategy training where weight shifting can be planned ahead, thus allowing the children to initiate a lower limb balance strategy (Michalski et al. 2012). Therefore, this game is recommended for children with CP; however, care must be taken to avoid forward sway because it might lead to falls or injuries. In addition, the children's preferences should be considered, as the scoring and feedback might affect the child's motivation.

3- Penguin Slide

This game requires the player to slide a penguin from side to side on an iceberg so it can catch the flying fish. The score reflects the number of fish the penguin catches within 60 seconds. The player's character is the penguin but the player's movement of weight shifting tilts the iceberg. The player must shift their weight from side to side to keep the penguin on the iceberg and prevent it from falling in the water. Sudden weight shifting is sometimes required to catch the flying red fish, each of which is worth 10 points. As the iceberg is a movable platform, the child trains their reactive postural adjustments by reacting to the movement of the iceberg.

This game combines cognitive and physical demands, as the child needs to decide in which direction to lean to catch the fish while keeping the penguin on the iceberg. All eleven children with CP enjoyed this game because the score of the game relies only on the number of fish collected, which was manageable. At the end of the game, the avatar penguin character cheered and danced with other characters. This was a pleasant motivation for children with CP, which contributed to recommending this game for balance training.

4- Table Tilt

The movement of the player in this game is represented by the movement of different shaped platforms. The player has to tilt the platforms to roll the balls across each platform and drop them through the holes. This game requires multi-directional weight shifting while leaning in a specific direction to move each ball toward the holes. The player is sometimes required to maintain a posture to stabilise the platform and prevent the balls from dropping off the edge of the platform. The game has nine levels and each level is timed. Level one, which lasts 60 seconds, starts with one ball and one hole. The number of balls or holes increases with each level, the shape of the table platform changes and the time limit decreases to increase the challenge. The number of levels achieved within the allotted time is calculated to provide the final score of the game.

In this game, children were weight shifting in different directions, meaning they were able to move their COG outside their base of support; this trained their postural control. As the visual feedback of the child's COP was reflected by the platform, the player could see the effects of their movement on the surrounding environment rather than the effect on the avatar character. This game contains simple visual graphics – colourful balls on a table – and no characters. The score is displayed in numbers without any sad characters responding to a low score. Therefore, the children with CP in this study showed a high preference for this game, as it was the most played game among the whole sample. In addition, as there were few distracting items in the game, the child was able to focus on weight shifting and maintaining their posture. This game is highly recommended for children with CP, as it increases the sense of achievement and most of the children were able to achieve level nine.

5- Tightrope Walk

In this game, the player is presented as a character that walks on a tightrope between two buildings and jumps over obstacles to each the other side. This game requires weight shifting from side to side while standing on the WBB to mimic walking; however, to make the character jump, the player needs to flex and extend their knees quickly without actually jumping. This could be good for training balance while walking, as it makes the child balance the weight between their lower limbs, and flexing and extending the knee is good for training knee control.

The visual feedback of this game is given in the instructions displayed on the screen to inform the player of where to shift weight to regain their balance, which was helpful for children to focus on the direction. The visual graphics of this game give the player a real sense of tension and fear of falling, which was beneficial for teaching the children how to bear weight in a balanced manner to avoid falling in real life. Additionally, this game does not present a crying character if the score is not achieved; the character cheers and dances with other characters when he reaches the next building within the time limit.

The player has two minutes to cross the tightrope. The time is displayed and counts down to show how fast the player completes the activity. Although speed is not enforced in this game, the game ends once the time runs out. Some children were able to perform the game but they needed more time to reach the other building. The game also automatically finishes when the character falls, which is a practical limitation, as the player needs to restart the game, which consumes time in the session. Most of the children enjoyed the challenge of the game and had a sense of achievement when they won. This game is recommended for balance training; however, two participants preferred not to play this game because of their fear of heights; this needs to be considered when choosing this game.

6- Balance Bubble

The player in this game is presented as a character locked inside a bubble. The player has to navigate the character down a river and prevent the bubble being popped by obstacles such as walls, rocks and bees. This game requires the player to shift their weight in all planes, as the bubble follows the player’s movement in all directions until the bubble reaches the rainbow. However, the main weight shifting for this game is in a forward direction, to move the bubble forward, with very limited side-to-side sway to keep the bubble away from things that might pop it. If the bubble is popped, the game ends automatically. This game requires much attention and decision making with few instructions. In addition, the forward weight shifting may not be recommended for children with CP due to their crouched posture (Burtner et al. 1998) and their anterior COG position moving their COP posteriorly (Winter 1995). As this game asks them to move their COP anteriorly, they are likely to lose their balance. Additionally, because their COP is positioned posteriorly, the bubble in the game tends to go backward and pop, thus ending the game.

This game is scored according to the time taken to complete the activity. This game does not provide negative feedback, as it ends with an error or a win. Although this is beneficial for the children, it is time-consuming to restart the game often. Six children favoured this game and enjoyed playing it; however, the other children did not like the visual graphics, which included too many items such as the trees, bees and rocks, which they found distracting. In addition, when the game ends regularly, the children begin to lose interest. We therefore recommend using this game with caution.

8.2 Recommendations for future RCT

The Wii Fit games are enjoyable for children with CP and are a cost-effective virtual reality modality available for clinicians, especially in developing countries. Studies that design new virtual reality games require considerable time and effort by engineers and graphic designers to design and assess these games' effectiveness as training tools. Therefore, conducting a study using available games is less time-consuming, taking previously raised points into consideration.

Following the feasibility outcomes of the present research, a RCT is feasible to conduct with the recommendations provided below, indicating the power calculation for RCT sample size, the participants' inclusion criteria, the recommended settings and training duration and the selection of Wii Fit games, and also including other forms of games, using other outcome measures to assess different effects of the Wii Fit games that were not tested in this research and which may be considered in future studies.

8.2.1 Sample size and recruitment

One of the main objectives of this feasibility study is to calculate a larger sample size using power analysis for the future RCT based on the standard deviation of one of the potential primary outcome measures. Following the discussion on the outcome measures used in this study, the PBS was selected as the primary outcome measure for the future RCT because the PBS data collected in this study was normally distributed and was analysed with a *t*-test. In addition, the MCID threshold for the PBS is known to be an increase of 5.8 points (Chen et al. 2013), which is essential for the sample calculation. The sample calculation method used was based on data with normal distribution and a *t*-test between two means of two groups (Machin et al. 2009). Therefore, to calculate a sample size with 80% power, the 5.8 difference between groups will be identified as a significant difference at the $p = .05$ significance level. The mean and standard deviation of the sample in this feasibility study at baseline was 46.18 ± 5.76 for the PBS. This was included in the sample calculation with the expected significant difference of 5.8. The sample calculation showed that in order to find significant differences between groups, 17 participants are required in each group with a total sample size of 34 participants, which is a feasible sample size.

Based on the recruitment rate discussed earlier, it is suggested that the future RCT should be conducted in Riyadh, Saudi Arabia. The estimated recruitment rate is 54.5% when recruiting from one physiotherapy clinic, and this rate is expected to be higher when participants are recruited from one of the schools for children with special needs. These recruitment sites are suggested due to the accessibility of identifying children with CP who might be eligible for the study. In addition, based on the earlier discussion, clinical and school settings are recommended instead of laboratory settings for a future RCT.

8.2.2 Inclusion criteria

The same inclusion and exclusion criteria used in the present feasibility study could be applied to a future RCT. However, this section discusses the possibility of including different ages and functional levels of children with CP for other future studies.

The present feasibility study included children with CP at GMFCS levels I-III due to their ability to stand and play the Wii Fit games. However, children with CP at GMFCS levels IV-V could be included in future studies when the training programme includes Wii Sports, which can be played while sitting, to assess sitting postural control. Children with CP who were described as postoperative and who were under intensive inpatient rehabilitation programmes were not included in this study because of the misleading effect of the surgery and the intensive rehab over the effect of the games themselves. However, it would be worth separately studying the effect of the games as part of the rehabilitation programme for this population.

In addition, the children's age in this study was limited to 6–12 years, an age range which was selected based on the development of postural control in TD children across different sensory systems. In addition, no studies have examined the milestone development of postural control in children with CP. This means that children who are younger than 6 or older than 12 might show different results based on their postural control development. Furthermore, children who are younger than 6 usually undertake regular clinic physiotherapy to reach a good functional level before the level plateaus, and children who are older than 12 usually do not continue a rehabilitation programme in which they might deteriorate (Hanna et al. 2009). Therefore, we recommend including children with CP between the ages of 3 and 18 in future studies by grouping them according to age, as it will give an insight into the effect of the games across different ages.

8.2.3 Intervention

The feasibility study included six Wii Fit balance games. Based on the earlier discussion of each game's suitability and acceptability for children with CP, the careful selection of games is important. The games recommended for future studies need to include simple visual graphics, minimal characters and positive feedback with respect to the score {no crying or disappointed characters}, and they should not be dependent on speed. Therefore, out of the six games presented in this study, the following three games are recommended for the future RCT: Table Tilt, Penguin Slide and Tightrope Walk. Two other games could be offered as options if the child is comfortable with playing them: Ski Slalom and Balance Bubble.

Therefore, four games were selected for this study, with two additional games included as options. This gave the children more options to enjoy and try different games, and having extra options was helpful when children preferred not to play the main games selected. In addition, randomising the games by including new games in different sessions might increase the children's motivation and enjoyment level and prevent the boredom of playing the same games repeatedly.

While this study only included Wii Fit balance games, other Wii Fit games are available that can be useful for training balance. Wii Sports has been shown to have an impact on balance, even though it is played with the Wii Mote, as it encourages midline turning and core stability (Deutsch et al. 2008). Therefore, we recommend selecting a mixture of Wii Fit games and Wii Sports games for future research.

Based on the findings from this study and existing literature (Abdel-Rahman 2010; Andrysek et al. 2012; Ferguson et al. 2013; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014; Tatla et al. 2014), a training period lasting between six and eight weeks is recommended. However, the children should participate in no more than three sessions per week to prevent boredom and fatigue and to maintain the participants' adherence and enjoyment levels. This means that balance improvements in children with CP should be evident within 12 – 24 sessions of Wii Fit games training. If this seems an impracticable length of training for future studies, we recommend using a convenient research setting, such as the school or clinic, to ensure a good adherence rate.

8.2.4 Outcome measures

In summary, all outcome measures used in this study were feasible for use in a future RCT. However, the COP length alone may not reflect the effect of the Wii Fit games. Other laboratory outcomes such as WBA, COP velocity and area, and walking trajectory might be more appropriate and realistic in terms of showing the differences in balance levels before and after playing the games. The PBS and TUG can be used as the primary outcomes in future studies. A combination of laboratory and functional measures in assessment is recommended in future studies for a more holistic functional assessment.

Laboratory outcomes such as the COP velocity, maximum sway in AP or ML directions and COP sway area would give a better assessment of the standing COP trajectory for a better judgment of the effect of the games on postural control. The WBA could also be used as an outcome of standing postural control, and it might be more suitable and practical for assessing the effect of Wii Fit games in future studies. However, these laboratory parameters would have been assessed rigorously through laboratory force plates instead of the WBB.

The functional balance outcome measures used in this study, the PBS and the TUG, were found to be feasible measures and are thus recommended for use in the future RCT. The PBS was selected as the primary outcome measure on which the sample size was calculated. However, as mentioned earlier, the PBS should be assessed by a blinded assessor of randomised groups to avoid bias, and the assessor should assess the children directly rather than through video recordings.

8.2.4.1 Recommended outcome mesures

Other outcome measures which could address different effects of the Wii Fit games on children with CP that were not used in this research will be discussed as suggestions for future studies. These outcome measures could assess the effect of Wii Fit games on overall GMFM or on sensory integration in children with CP. Each one will be discussed separately.

8.2.4.1.1 The gross motor function [GMFM]

Limited studies have investigated the effect of Wii gaming {Wii Sports or Wii Fit} on GMFM in children with CP (Gordon et al. 2012) and children with developmental delays (Salem et al. 2012). Gordon et al. (2012) showed clinically significant changes in mean pre- and post- training scores for all GMFM dimensions in six children with CP. Salem et al. (2012) showed significant improvements in the GMFM dimensions D and E from pre- to post- intervention for 20 children with developmental delays. Although both studies used small samples of children, they both showed the potential effects of Wii gaming {Wii Sports and Wii Fit games} on GMFM. However, more studies are needed to investigate the effect of Wii Fit games on GMFM for children with CP.

The present study looked at the effect of Wii Fit balance games on standing postural control, functional balance and mobility. The effect of Wii Fit balance games on GMFM was not tested in this study, although balance games that include training for standing, weight shifting, strength and balance might contribute to improvement of the overall GMFM in children with CP. Therefore, including the GMFM-88, GMFM-66, or even part of it such as dimensions D and E, as an outcome measure in future studies will give insight into the effect of these games on overall functional level as well as just on balance.

In addition, when using the GMFM-66 the MCID threshold increases the overall score by 1.3. An increase of 1.8 of the total score of dimension D {standing}, or an increase of 2.6 of the total score of dimension E {walking, running and jumping} of the GMFM is considered a significant improvement for children with CP (Oeffinger et al. 2008). Therefore, the MCID threshold of the GMFM-66 or dimensions D and E are not high and are thus considered reasonable and realistic to achieve significant changes in children with CP. This is another convenient reason to recommend the use of the GMFM-66 in future studies.

8.2.4.1.2 Sensory integration

Sensory integration dysfunction is one of the most important problems seen in children with CP. Children with CP experience some sensory perceptual problems, such as impairment of body image, right-left discrimination, position in space and visual perception problems and apraxia (Goldcamp 1984). Sensory integration therapy has been shown to be effective therapy for children with CP (Bumin & Kayihan 2001; Shamsoddini & Hollisaz 2009).

The Wii Sports games have been shown to improve motor proficiency, visual-integrative abilities and sensory integrative functioning in children with DS (Wuang et al. 2011). Wii Sports games encourage children to actively explore and organise various sensory inputs, which may subsequently enhance motor planning and increase visual motor integration and coordination between limbs (Wuang et al. 2011). This may also be true for Wii Fit games; however, this theory has yet to be investigated in children with CP. Nevertheless, Wii Fit games are not only a motor learning technique by which to weight shift in a task-specific way; they can also possibly constitute a sensory integration tool that encourages motor learning. The present study has only focused on the motor effect of balance training while playing the Wii Fit games. Therefore, it is worth investigating the effect of the games on sensory integration as a neuromotor learning process to maintain postural control.

The Southern California Sensory Integration Tests [SCSIT] (Ayres 1972) are the clinical assessment tools of sensory integration. Although they have not been tested for validity and reliability for children with CP, they have been shown to correlate highly with the BOT-2, and can thus be used to evaluate the effectiveness of sensory integrative procedures in relation to motor function

(Ziviani et al. 1982). This means that the BOT test is recommended as an outcome measure for future studies to reflect the effect of Wii Fit games on sensory integration for children with CP.

8.2.4.2 The ICF model

The World Health Organization has formed a conceptual framework, which is the ICF, to classify health and health-related domains (WHO). The ICF model covers three main levels; body structure and function level, activity level, and participation level. This universal model provides a useful way of designing proper treatment interventions and selecting outcome measures. It is good practice to select outcome measures which cover the main three levels of ICF. However, due to the diversity of outcome measures, it is hard to find an outcome measure which covers all ICF levels. This is mainly due to the variety of aspects which each measure was designed for. Therefore, the three levels of ICF could be covered by selecting more than one outcome measure.

This study used three outcome measures which were, the COP length via WBB, to assess standing stability, the PBS and the TUG, to asses functional balance and mobility. The COP parameters, either collected from WBB or force plate, are a laboratory measures which assesses postural control. These measures cover the body structure and function level of the ICF model. The PBS is a clinical functional measure of balance, which includes items testing the ability of maintain balanced position, and the ability to perform balanced activity. Therefore, this measure covers two levels of the ICF model; the body structure and function level and the activity level. The TUG is a single item measure of walking balance which only covers the activity level of ICF model.

In addition, this study suggested including the GMFM-66 , to assess overall gross motor function, and the BOT-2, to assess sensory integrative procedures in relation to motor function. Both measures are multidomain measures were most items covers the activity level of ICF model. In order for a future RCT to include outcome measures that cover all levels of ICF model, there should be an outcome measure that covers the participation level of ICF. The Children's Assessment of Participation and Enjoyment [CAPE] (King et al. 2007) and the Pediatric evaluation of disability inventory [PEDI] (Haley S et al. 1992) are both examples of outcome measures that covers the activity and participation levels of ICF. Therefore, it is recommended for future RCT to use either the CAPE or the PEDI to assess the effect of playing Wii fit games on the child's participation and social interaction.

8.3 Novel contribution

The novelty and originality of this research is highlighted from the three studies, including two reliability studies of WBB with children with and without CP and a feasibility study using Wii Fit games for balance rehabilitation for children with CP. The novelty of the results from each study is presented in relation to the time when the study was conducted and the new publications of similar studies.

8.3.1 Reliability studies

This research started in 2012, when only a few studies investigated the applicability for WBB for balance assessment (Clark et al. 2010; Clark et al. 2011). Owing to a lack of clarification of the functioning of the WBB, more work needed to be done regarding interpreting the WBB data using other programmes (Chapter 4). This has highlighted reference data, which were not available in existing literature at the time, indicating the minimum weight limit the WBB can measure [10 kg], the difference between two WBB measurements, the importance of calibration and the difference between the Kistler force plate and the WBB in measuring COP sway. These original findings were valuable for addressing the reliability and usability of the WBB in assessing balance for research or clinical purposes.

The few studies found in the literature were conducted with adult populations and not with children. This gap in the literature was filled with the reliability study (Chapter 5), conducted in 2012, which investigated the reliability of WBB's COP data when assessing TD children. This study provided original reference data for the reliability of WBB COP length for TD children, which were essential before using the WBB to examine children with CP. However, within the last three years, more researchers have investigated the reliability and validity of WBB outcomes to assess standing balance (Chang et al. 2013; Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Holmes et al. 2013b; Bower et al. 2014; Larsen et al. 2014; Park & Lee 2014; Scaglioni-Solano & Aragon-Vargas 2014; Sgrò et al. 2014; Abujaber et al. 2015; Jeter et al. 2015; Pavan et al. 2015). Among these, the Larsen et al. (2014) study was the one which reported the reliability and validity of using the WBB to assess balance in TD children. This means that the originality and novelty of the reliability results of Chapter 5, have been eradicated with the publication of Larsen et al. (2014), even though the results presented in chapter 5 confirmed these researchers' results despite the age range being larger than in their study. By contrast, the second reliability study (Chapter 6), which was performed on children with CP, was, to the author's knowledge, the first to investigate the reliability of the WBB in providing the COP length of children with CP during standing. Therefore, the results of the second study are considered original and novel.

A unique feature of both reliability studies is that each standing task was assessed separately {EO2L, EC2L, EO1L, EC1L}, whereas other studies reported an average of all the standing tasks performed (Clark et al. 2010; Clark et al. 2011; Chang et al. 2013; Huurnink et al. 2013; Yamamoto & Matsuzawa 2013; Holmes et al. 2013b; Park & Lee 2014; Pavan et al. 2014; Pavan et al. 2015). This is valuable information in distinguishing the difference in the reliability results of each task and identifying the practicality of each task for children.

Lower ICC values were recorded for the single-leg standing tasks for TD children and for the task of the children with CP standing with eyes closed. However, by using Bonett's (2002) formula with the ICC values results in these studies, the sample size required in order to test the reliability of COP length during single-leg standing for TD children with a desired width of 0.3 is 25 participants, and 78 participants are required for the test of double-leg standing with eyes closed for children with CP. This research provided the recommended sample size for future studies to further investigate the reliability of WBB COP length during these tasks.

Although researchers in the literature and the results of the reliability studies agree that the WBB has been shown to be reliable and valid when assessing balance, the WBB cannot replace the gold standard laboratory force platforms. This is because the WBB was not designed for this purpose. Therefore, this research not only included original work starting with investigating the WBB data extracted to test the reliability of the calculated COP length when assessing children's balance, it also highlighted several feasibility points which need to be considered before recommending the WBB for clinical use. These feasibility aspects, including the time of connection, calibration and coding of programming for COP parameter calculations, were discussed earlier in section 8.2.1. This feasibility discussion was not highlighted in previous literature, as this research was the first to actually use the WBB in clinical settings and to use the WBB COP length as an outcome measure to investigate the effect of an intervention.

8.3.2 Feasibility study

The feasibility study was designed when only limited research was found in the literature regarding the effect of Wii Fit games on balance for children with CP (Ramstrand & Lygnegård 2012; Sharan et al. 2012). None of these studies had a randomised control group to show the pure effect of the Wii Fit games as balance rehabilitation tools for children with CP, therefore an RCT was needed. However, this study was not intended to be RCT to show the effectiveness of the Wii Fit games but rather to assess the feasibility of designing and conducting a future RCT based on the present study's findings. At that time, it was the first study to consider Wii Fit balance games as a balance rehabilitation tool in clinical settings, unlike the home settings presented in

Ramstrand & Lygnegård (2012), and for a sample of children with CP {GMFCS I,II,III} from the community, unlike the sample of post-operative children with CP in the Sharan et al. (2012) study. These differences were highlighted as an original area of research that has not yet been covered. However, when this study was conducted in 2013, new research had been published which included clinical settings and a sample of community children with CP with GMFCS I, II and III (Jelsma et al. 2013; Tarakci et al. 2013). These studies, which were conducted with small sample sizes of around 14 participants, cannot be disseminated with confidence and need more power to be considered as evidence.

This study feeds into the literature with original findings showing that playing Wii Fit balance games twice a week for four weeks does not improve or affect the standing postural control or functional balance mobility of children with CP. Although these results failed to show any significant effect of the Wii Fit games due to sample limitation, various feasibility points were observed and discussed for consideration when conducting the future RCT (section8.1.2). These points have led to novel recommendations for future studies that were not mentioned in previous studies (section8.2). This study calculated the sample size required with an 80% power to identify the true effect of Wii Fit games on functional balance measured with PBS; this sample size is 34 participants with 17 participants in each group.

This study was the first to use the WBB, which is a required tool for Wii Fit games, as a balance assessment tool; it has also demonstrated the feasibility and potential use of the WBB for assessments in clinical rehabilitation settings for children with CP. Furthermore, to the author's knowledge, the present study is the first to mix clinically functional measures {PBS and TUG} with laboratory outcome measures {COP length} to assess the effect of Wii Fit balance games on children with CP. However, studies found in the literature have used either laboratory outcome measures (Ramstrand & Lygnegård 2012)or clinical balance measures (Sharan et al. 2012; Jelsma et al. 2013; Tarakci et al. 2013).

The present study also assessed the levels of enjoyment experienced by children with CP by filling out the PACES, which is a valid measure of enjoyment for children (Moore et al. 2009). High levels of enjoyment were recorded, as the children perceived the games as fun activities rather than as training exercises. Although existing literature has reported that Wii Fit games are enjoyable for children with CP (Ramstrand & Lygnegård 2012; Sharan et al. 2012; Jelsma et al. 2013; Tarakci et al. 2013), none study tested the level of enjoyment with a valid measure.

Feedback from children with CP in this study was considered for each of the Wii Fit games used, and an in-depth discussion was conducted based on the acceptability for children with CP and the postural technique used while playing each game (section 8.1.2.6). This is a novel and original game review for children with CP, which provides important information to know before introducing Wii Fit games to the rehabilitation programme as a new intervention tool.

8.4 Limitations

Regardless of the original findings, caution must be taken when disseminating these results due to the limitations acknowledged for each study of the present research.

8.4.1 Reliability studies

The disrupted connection between the WBB and MATLAB® caused by other Bluetooth devices caused repetitions in time acquisition and missing data points in the recordings. Subsequently, some recordings had a smaller amount of data points, reducing the quality of the total COP path length calculation. To compensate for this error, data were pre-processed to remove spurious outliers or repeated data points. This provided an outcome of COP path length per time unit [cm/sec], which cannot be represented as the total COP length or the COP velocity.

The COP length per sec was the only measure calculated from the WBB's data and tested for reliability among children. Other COP parameters, such as COP velocity, maximum sway in the AP or ML directions or COP sway area, were not calculated or tested for reliability in the present study.

None of the reliability studies compared the WBB's recordings to the force plate recordings for children. Even though previous studies have shown valid COP outcomes using the WBB to assess balance in adults and children, this research did not test the validity of the COP length with the WBB to assess children with CP.

Another major limitation of the present study was the small sample size of 12 participants in both studies, and not all participants performed the tasks successfully. For example, in Chapter 5, the results for task 4 [EC1L] were based on recordings of seven TD children who could perform the task on both the test days, whereas 25 TD children is the required number of participants to perform this task. In Chapter 6, the results for task 2 [EC2L] were based on recordings of eleven children with CP who could successfully perform each task three times, whereas the required number of participants to perform this task is 78. Therefore, the missing data in the small sample size for the study limits the ability to draw general conclusions from the findings.

8.4.2 Feasibility study

The absence of a control group or randomisation, as seen in an RCT, limits the ability to assess the true effect of the Wii Fit games compared to an RCT. However, this feasibility study aimed to show the feasibility of designing and conducting an RCT to test the true effect of Wii Fit games rather than their effectiveness.

This feasibility study contained a sample of 11 children with CP, with age range between 6 and 12 years and GMFCS levels I-III only. Therefore, the results were limited by the low power of the small sample size, as this sample was too small to show a significant difference. In addition, the sample did not include children who were younger than 6 years or older than 12 years of age , and it did not include children with CP at GMFCS levels IV-V. Therefore, the sample was not representative of children with CP at all GMFCS levels. These results should therefore be disseminated with caution.

The setting in the present study was a laboratory room at the university, which was inconvenient for children and their parents to attend. The need to travel to the laboratory after school placed an extra burden on the participants’ families {parents and siblings}, especially when the children were involved in extracurricular activities. As a result, the participants were only able to attend twice a week instead of three times a week, which decreased their training intensity. However, the feasibility of other settings, such as schools or clinics, and the impact that these settings would have on the results were not investigated.

The intensity and duration of the training chosen for this study was 30 minutes, twice a week for four weeks, giving a total of eight sessions. This was shorter than the training period of six to eight weeks used in the literature (Abdel-Rahman 2010; Andrysek et al. 2012; Ferguson et al. 2013; Mombarg et al. 2013; Hammond et al. 2014; Jelsma et al. 2014; Tatla et al. 2014) to show the effect of training with Wii Fit games. As these studies were published when the present study was in progress, it was impossible to follow the recommended durations. Therefore, the short duration and intensity of the training was a limitation in this study.

The Wii Fit games used in this study included only six selected balance games, however other Wii Fit games like aerobics, strengthening or yoga games and Wii Sports games were not used in this study. This means that the results are limited to six Wii Fit balance games while other forms of games may have shown different outcomes. In addition, the in-depth game review for children with CP was based on verbal feedback from participants, which was not provided through any qualitative methods, it was also limited to the six games played in this study.

The outcome measure used to assess the effect of Wii Fit games on standing balance was the COP length per sec measured via the WBB rather than via a laboratory force platform, the first time the WBB was used for children with CP. This calculated COP length per time from the WBB has not been tested for validity, as it was only tested for reliability with children with CP, who were the same sample used for the feasibility study. In addition, the Wii Fit games require swaying or weight shifting in multiple directions, which could improve symmetrical weight-bearing while standing and walking. By contrast, the COP length is an outcome of standing static stability; therefore, the selected outcome measure did not reflect the desired effect of the game. However, the WBA could have been a more suitable and practical outcome measure for assessing the effect of Wii Fit games. Furthermore, other COP parameters, such as COP velocity, maximum sway in the AP or ML directions or COP sway area, were not used to assess static standing postural control in the present study. These parameters may have provided a better assessment of the standing COP trajectory and thus allowed a better judgment of postural control.

The present study was limited to assessing the potential effect of Wii Fit games on postural control and functional balance mobility. However, other effects such as the effect on overall GMFM or the effect on sensory integration for children with CP were not assessed. In addition, the absence of qualitative research methods, such as interviews or focus group discussions, was a further source of limitation in the present study. These methods could have provided an insight into user perceptions regarding the feasibility of using the Wii Fit games in rehabilitation programmes. Such information is crucial and would influence the choice of Wii Fit games as a clinical rehabilitation tool.

8.5 Clinical relevance

Clinicians may benefit from using the WBB to bridge the gap between laboratory quantitative objective measures of standing and the subjective rating measures of functional movement. However, the WBB cannot replace the gold standard laboratory force platforms because it was designed for the purpose of playing games by communicating with the Wii console. Therefore, using the WBB as a balance assessment tool in clinical settings is not a straightforward procedure and few feasibility considerations were highlighted. First, the connection procedure between the WBB and communicating software through Bluetooth and the open source library [WiimoteLib]. In addition, Bluetooth disconnection or connection disturbances caused by other Bluetooth devices are possible problems that could affect the data transfer between the WBB and the laptop, thus leading to errors in recordings. Subsequently, a calibration protocol is required to reset the calibration factors of each sensor before extracting data from the WBB's sensors. This will require collecting data from the WBB when no weight is applied, and then when a standardised weight is applied. The location of the applied weight also needs to be made known to the software programme to calculate the calibration factors. Regular calibration process is mandatory when working with the WBB as it needs to be calibrated every time it has been moved, due to its portability. Moreover, the software should be programmed with a list of mathematical calculations to calculate the resultant COP coordinates then the COP parameters such as mean velocity or COP length, which include distance and time, can be further calculated. However, such software requires people with experience in software coding, which could be inconvenient for clinicians. Therefore, a commercially available user-friendly software for clinical usage is needed.

The Wii Fit games are enjoyable for children with CP and are a cost-effective virtual reality modality available for clinicians, however, the evidence behind its effectiveness in balance training is still limited. Therefore, a larger powered sample for an RCT is needed to identify the effect of Wii Fit training on balance for children with CP. However, this study was not intended to be RCT to show the effectiveness of the Wii Fit games but rather to assess the feasibility of designing and conducting a future RCT based on the present study's findings. Even though, this study highlighted some feasibility aspects of using the Wii Fit games in clinical settings. First, the time consuming during the set up of the Wii Fit including connection with WBB and the initial measures of the child's weight and balance before starting with the games. Although this process may be as short as five minutes, it may not be feasible for clinicians who provide 30 min session. In addition, as the Wii Fit games requires movement while standing on the WBB, it is essential to ensure the safety arrangements to protect children from falling including the WBB protective rubber, protective floor mats, and the use of the safety-handling belt. These arrangements are also time and space consuming which may not be feasible for come clinicians. Furthermore, as these games were not designed for a rehabilitation purpose, clinicians must be careful when using them for rehabilitation of children with CP. For example, when selecting a game, which will train a movement for a therapeutic purpose, care must be taken to select a suitable game with simple visual graphics, minimal characters and positive feedback with respect to the score {no crying or disappointed characters}. Supervision and observation of the child movement during playing is also important to ensure that the child benefit from playing the game by giving instructions about how to properly weight shift to win the game. With considerations of all points discussed, the Wii Fit games can be one of the rehabilitation intervention tool, which can benefit in training weight shifting with visual feedback for children with CP. The Wii Fit is an optional intervention in balance rehabilitation depending on the evidence of its effectiveness from the future RCT/ studies.

8.6 Final conclusions

8.6.1 WBB as balance assessment tool

1) The WBB provides reliable outcomes in terms of COP length when assessing the double-leg stance with eyes open or closed in TD children; however, poor reliability results were recorded during the single-leg stance assessments in TD children.

2) The WBB provides reliable outcomes in terms of COP length when assessing a double-leg stance with eyes open only in children with CP, while poor reliability results were achieved when assessing the double-leg stance with eyes closed in children with CP.

3) The high technology, portability, cost-effectiveness and commercial-availability of the WBB can benefit clinicians in bridging the gap between laboratory quantitative objective measures of standing and the subjective rating measures of functional movement.

4) The WBB cannot replace the laboratory force plates, because the WBB was mainly designed for the purpose of playing games through communicating with the Wii console.

5) The process of connecting the WBB to software and the calibration of WBB is time-consuming in clinical and research settings. More user-friendly software is required to programme and connect with the WBB via a proper calibration process to enhance the use of the WBB in a clinical setting.

6) Excellent reliability of the WBB readings was reported despite the small sample size. Further studies with larger samples are recommended, especially for the challenging tasks which recorded poor reliability.

8.6.2 Wii Fit games as balance intervention tool

1) The use of the Wii Fit balance games twice a week for four weeks did not significantly improve standing postural control or functional balance mobility in children with CP. However, the small sample size limitations along with the research setting and short training period limits the generalisability of the feasibility study findings and suggests caution in the dissemination of the findings.

2) The sample size required with an 80% power to identify the true effect of Wii Fit games on functional balance by PBS is 34 participants with 17 participants in each group.

3) This study explored the following feasibility consideration points for designing an RCT to test the true effect of Wii Fit games:

   A) The estimated recruitment rate in Riyadh, Saudi Arabia, is 54.5%.

   B) School or clinical settings are recommended more than a laboratory setting, which was not convenient or feasible for children and their parents.

   C) The WBA could reflect the effect of Wii Fit games more than the COP length, which assesses static stability. Other COP parameters assessed with laboratory force plates could provide a better assessment of the standing COP trajectory to show the effect of the games on postural control.

   D) A longer duration and a higher intensity of training, ranging from 12 to 24 sessions, is recommended.

   E) Based on the children’s feedback from the Wii Fit games, games with fewer visual graphics, fewer characters, no crying or disappointed characters and game scores that do not depend on speed are considered the most suitable games for children with CP.

   F) Children with CP expressed 75%–100% adherence to the Wii Fit training, which showed high motivation levels. The enjoyment level was represented by a rating of 3.5 out of 5 for the PACES of positive statements of enjoyment.

4) An RCT with a control group and randomisation of a larger sample is feasible, doable, applicable and worth conducting with different circumstances such as a longer training period, convenient research settings, more outcome measures and the proper selection of the games used for training.

Appendices

Appendix 1: Clark et al. (2010) calibration and calculation appendix

Calibration Steps

The steps taken in the calibration of the BB are based on those outlined by Bobbert et al. [1], with specific modifications made due to the limitations inherent in the Wii Balance Board (WBB). These steps are as follows:

1. Convert the data from each of the four sensors into a true force value. The basic calibration information provided in the data stream from the WBB was used to determine force in each sensor, however to ensure the precision of these values a calibration protocol was implemented. This was performed by recording the raw data while applying six different known loads (49.1N, 74.6N, 102.0N, 113.8N, 215.8N, 313.9N) to each of the sensors individually. Regression performed on the calibrated force data showed that for each sensor the relationship between increased load and the absolute value recorded for that sensor was linear, with the linear regression equation for every sensor exceeding R2 = 0.999. This shows that, once calibrated, each individual sensor has a linear response to applied load, which allows for accurate assessment of forces which are not identical to the calibration loads used.

2. Calculate the Z force. Force in the vertical plane (Fz) was determined by summing the values for each of the four sensors then multiplying this value by a scale factor. This scale factor was derived by placing the known loads mentioned previously on the balance board and dividing the known load by the sum of the four transducers. Similar to the results for the individual sensor calibration, this showed excellent linearity.

3. Determine the COP coordinates. The COP positional data was then determined for the X (Xcop) and Y (Ycop) axes using the equations:

$$Xcop = \frac{0 - TL - BL + TR + BR}{Fz} \times CALx$$

$$Ycop = \frac{0 - BL - BR + TL + TR}{Fz} \times CALy$$

Where BL, BR, TL and TR are the calibrated force values from the bottom left, bottom right, top left and top right sensors respectively and CALy and CALx are the calibration factors specific to each axis. These calibration factors were necessary to correct for the different distance between the sensors and the true center position for each axis, and were determined by placing a variety of known loads at a number of known positions on the board. Given that the true central position of each sensor was not known, the individual axes calibration factors were derived using the equations:

$$CALx = \frac{Xpos}{\frac{\Delta Xcop_{(uncalibrated)}}{\Delta F}}$$

$$CALy = \frac{Ypos}{\frac{\Delta Ycop_{(uncalibrated)}}{\Delta F}}$$

Where Xpos and Ypos are the known axis positions of the applied load, F is the force applied and Xcop(uncalibrated) and Ycop(uncalibrated) are the results of Equation 1 if the calibration factor is set at a value of 1.

Assessment of the COP coordinate calibration values

To assess the COP coordinate calibration a range of known loads were placed at a number of different positions on the Balance Board. This was performed by placing a calibration grid on the Balance Board, which was created by marking eight points on the board which formed a grid around the centre of the balance board. Four points corresponded to a diagonal position in each direction 40mm from the centre of the board, with the remaining four points located at a diagonal position 60mm from the centre of the board. A variety of different loads were intermittently placed on each of these points. The average percentage difference between the calculated COP coordinates and the known position of the applied load were 2.3 + 2.0% and 2.9 + 1.9% for the X and Y axes respectively. This close approximation of the calculated COP coordinates with the known loading position suggests that the BB provides an accurate measure of static COP.

Limitations

Given the low-cost nature of the device there are a number of limitations inherent in using the WBB as a force platform to assess COP coordinates. These include the eight byte signal and sampling frequency restrictions. When compared with a force platform, the primary limitation is the inability to correct for forces in the X and Y axes. The importance of this is evident when the COP axis equations of Bobbert et al. (1990) are examined, for example:

$$Ycop = \frac{Z * Fy + b((TL + TR) - (BL + BR))}{Fz}$$

Where Z = the vertical distance between the working plane of the forces and the surface of the testing device, Fy = y axis force and b = half the distance between the transducers along the y-axis.

The lack of X and Y axes force values therefore removes a component of the true COP equation, and consequently it was important to determine how much of an effect this had on the results. Analysis of the results of the force plate data revealed that, as expected, the magnitude of the X and Y axes force during the standing balance tasks was minor. For the double leg tasks it was rare for the force values in either of these axes to exceed +5N, and therefore this would have only a negligible influence on the results of the primary outcome measure of the present study (COP path length). Additionally, the X and Y axes force data during the most difficult standing balance task performed in this study, the single leg, eyes closed trial, rarely exceeded a threshold of +10N with short duration peaks of ≈+30N. Given that this was a small percentage of the Z axis force (<5%), and that the vertical displacement multiplier (which represents the vertical distance between the working plane of the forces and the surface of the testing device (Bobbert & Schamhardt 1990)) which would be used in the equation is relatively small (for the WBB, approximately 33mm), we feel that the processed WBB COP data is a reasonable representation of standing balance during tasks which do not have a large horizontal plane momentum component. To verify this assumption we performed a series of tests on a Kistler force platform (model 9286AA) incorporating each of the balance tests performed during the present study. The COP data for each axis was then compared between the manufacturer's software (Bioware 3.0) and the Bobbert equation performed with a static Fy value of 1. Even during the trial with the highest observed X and Y axes forces (single leg, eyes closed) the correlation between the different COP coordinate values exceeded R=0.95. While this supports the use of the WBB for assessing COP during trials with low horizontal plane forces, due caution must be taken when comparing the absolute results of the balance board COP data with those obtained from a force plate

[1] Bobbert MF, Schamhardt HC. Accuracy of determining the point of force application with piezoelectric force plates. Journal of Biomechanics 1990; 23(7):705-710

Appendix 2: ETT Stance Manual guide

ETT STANCE

User's Manual

Sistema Qualità Certificato
UNI EN ISO 9001:2000
9151.ETT4 IT 35024

ETT s.r.l.
Via Sestri 37 16154 Genova Tel: +39 010 6018260 Fax: +39 010 6091202
Partita IVA/Cod. Fisc.: 03873640100
e-mail: info@ettsolutions.com Internet : http://www.ettsolutions.com

1. Content

2. WII Balance Board Connection

To correctly use WII Balance Board with Stance software you need to connect the board to the computer on which Stance is installed, using a bluetooth connection.

To establish this connection you have to follow these steps:

1. Activate the bluetooth service installed on your pc (using a dongle key or the integrated connection);
2. Switch on the WII Balance Board;
3. Search for new bluetooth peripherals, (from “Bluetooth -> Search for new devices”) and, at the same, press the “SYNK” button of the Balance Board (placed in the batteries box).
4. When the pc finds the WII Balance Board, click with the right button of the mouse on the board icon, select the option “Update Services” and connect the PC with the service “Human Interface”

After all these actions, the WII Balance Board is properly connected and can be used with Stance.

N.B.:the user must do all the actions described every time he switch on the pc to use Stance

3. Stance Software

3.1 Run Stance

Stance can be run from your computer by clicking the Application icon in project directory.

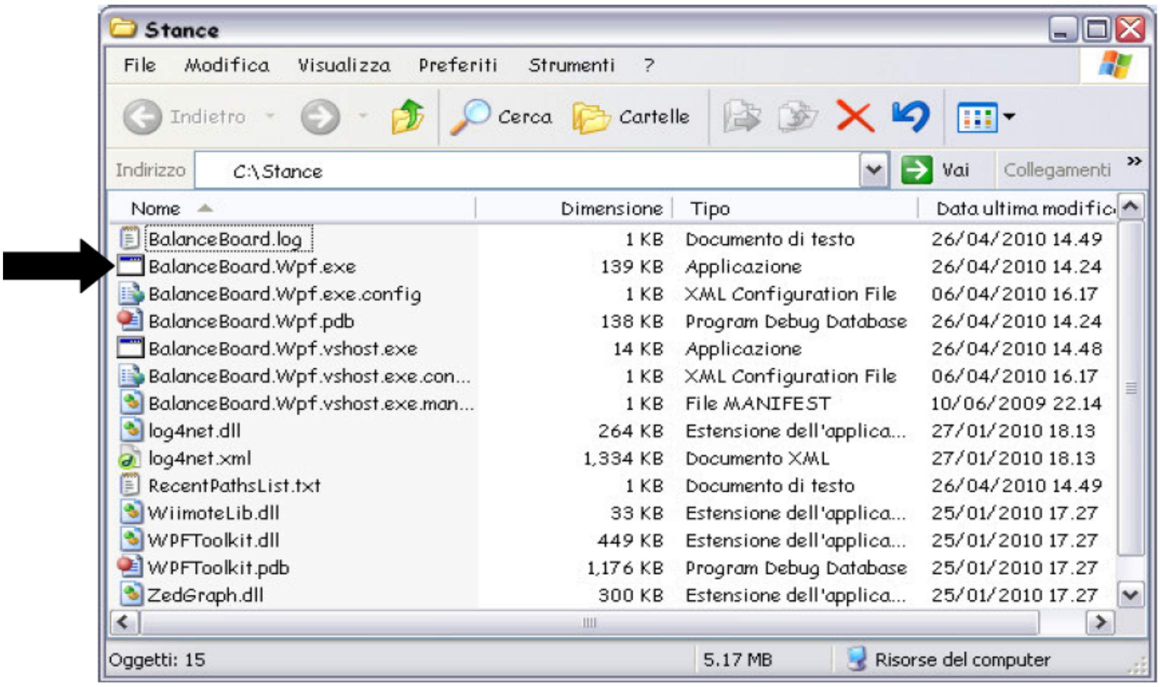


Figure 1: Run Stance

3.2 Chose directory

You can choose in which directory store the collected data. To do this, you have to select the  icon in the main window, that opens the following panel:

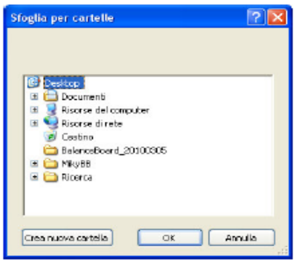


Figure 2: choose directory

Here you have to select the desidered folder. To view the data already saved in the selected directory, press the  button.

3.3 Patients module

The Patient Module permit to create a new patient or to modify or delete the data related to any stored patient.

Create a new patient.

To create a new patient use the button  in the Menu Bar in the main panel as in Figure:

Figure 3: new patient creation

After this selection the Subject panel is loaded:

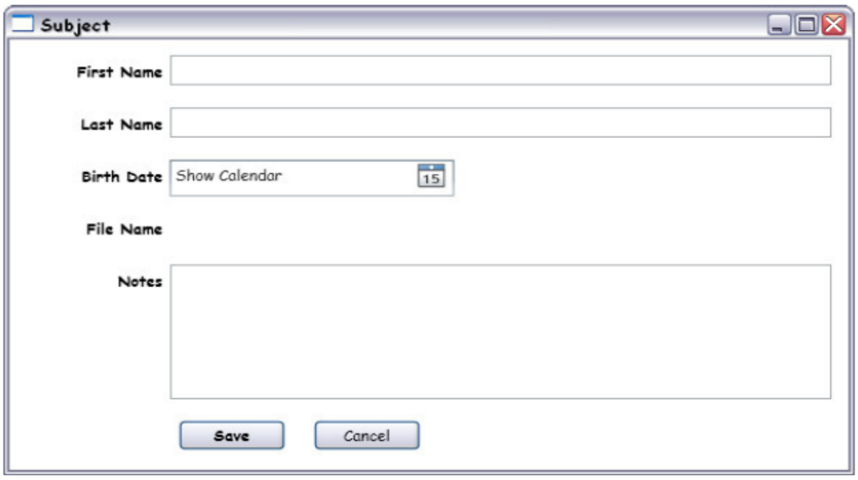


Figure 4: Subject panel

Compile the textbox in the creation patient panel and click the "Save" button to save the new patient.

You can find the saved data in Stace main window, as a list of patients:

Figure 5: Subject's data

Delete a patient.

To delete patients' data, you have to right click on patient's name in patients' list and to chose "Delete Subject"

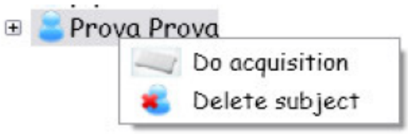


Figure 6: delete patient's data

3.4 Protocol module

The Protocol Module permit to create a new protocol.

To create a new patient use the button  in the Menu Bar in the main panel as in Figure:

Figure 7: new protocol creation

After this selection the Protocol panel is loaded:

Figure 8: Protocol Panel

Patients will perform the inserted protocol until i twill not be changed following the same procedure.

3.5 System Calibration and Data Acquisition

Before starting the data collection, you must verify if the WII Balance Board is correctly connected and calibrated. To verify these conditions, you have to right click on patient's name and chose the option "Do Acquisition":

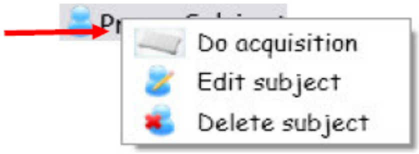


Figure 9: Acquisition

If the board is properly connected, on the window top right corner you can see the  icon, otherwise you will se the  icon.

4.3.1 System Calibration

To correctly calibrate the WII Balance Board you have to perform the following actions:

1. Click on  icon to open the calibration panel
2. Select the WII Balance Board in the panel
3. Put a known weight on the WII Balace Board and push the "Calibrate" button
4. Wait until you see the calibration is done (until a software pop-up)

Prima di utilizzare il software per acquisire i dati è necessario calibrare la balance board.

4.3.1 Data Acquisition

To start a new acquisition you have to right click on patient's name and chose the option "Do Acquisition". When the patient is on the WII Balance Board, click on the "START" button to start the acquisition.

Figure 10: start the data Acquisition

During the acquisition you can see in real time the graphs which describe the Centre of Gravity (COG) position and it x and y coordinates:

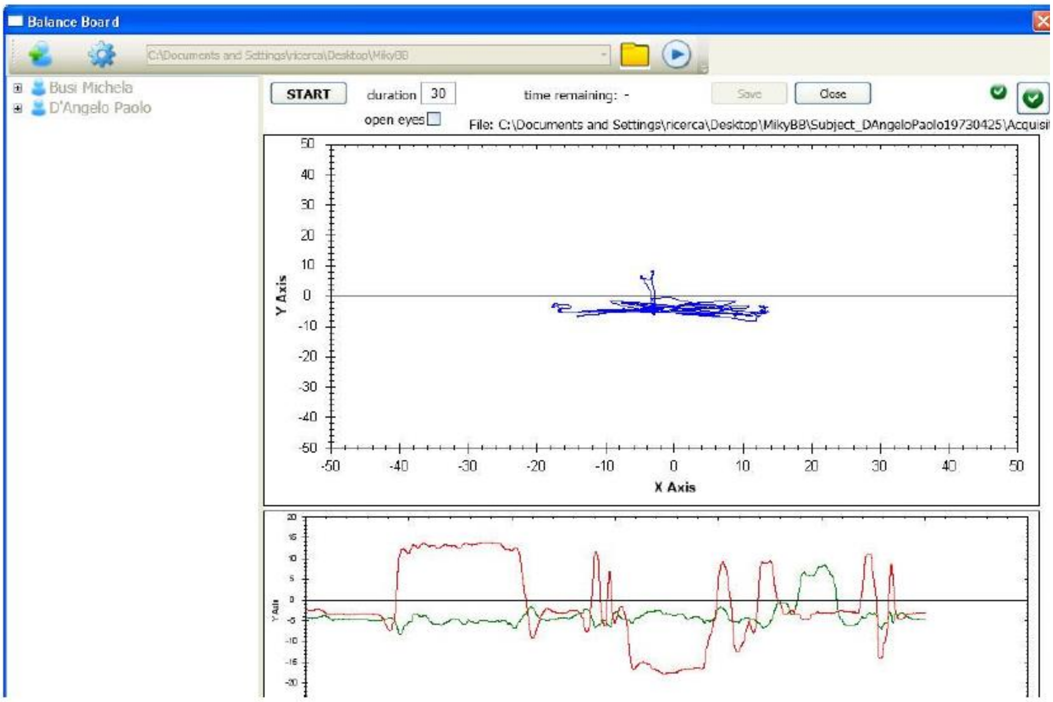


Figure 11: Acquisition Graphs

To stop the acquisition you have to push the "STOP" button.

All the data are saved in the chosen directory, in a folder dedicated to the patient. You can manage those data by clicking on the "+" near patient's. Doing this you can see all the performed acquisition:

Figure 12: Acquisitions list

To manage the collected data you have to right click on the desidered acquisition:

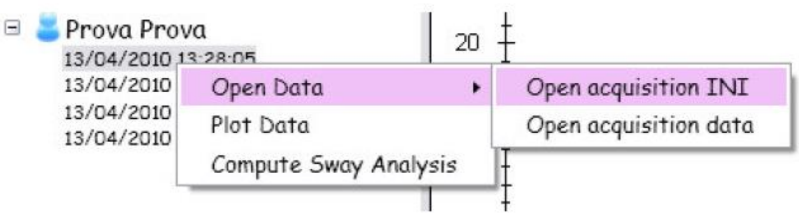


Figure 13: data management

You can:

1. open the collected data, both the raw data and their ini file
2. Plot Data, redrawing the related graphs
3. Compute sway analysis, to calculate the specific parameters related to sway analysis:

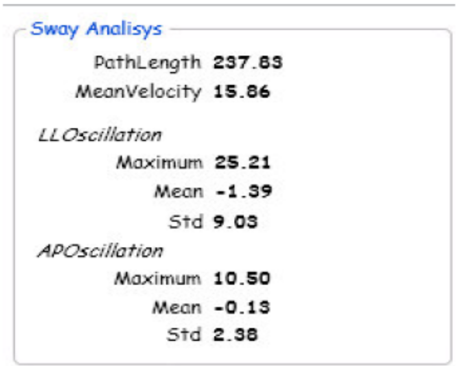


Figure 14: sway analysis

Appendix 3: MATLAB coding for COP calculation

```
function varargout = BalanceTest(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
    'gui_Singleton',  gui_Singleton, ...
    'gui_OpeningFcn', @BalanceTest_OpeningFcn, ...
    'gui_OutputFcn',  @BalanceTest_OutputFcn, ...
    'gui_LayoutFcn',  [] , ...
    'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end
if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
return



% --- Executes just before BalanceTest is made visible.
function BalanceTest_OpeningFcn(hObject, eventdata, handles, varargin)
global data
% connect to the Wiimote
data.wm1 = Wiimote();
data.wm1.Connect();   % wiimote
data.wm1.GetBatteryState;
disp(sprintf('Battery Status of Wiimote: %3.2f%%',data.wm1.Battery));
% connect to the Balance Board
data.bb = Wiimote();
data.bb.Connect(); % balance board
data.bb.GetBatteryState;
disp(sprintf('Battery of Balance Board: %3.2f%%',data.bb.Battery));

data.WiiWidth=21.7;
data.WiiHeight=11.7;
data.sr=50;
% data.edit1=data.sr;
data.duration=20;
% data.edit2=data.duration;

data.isrunning=0;

set(handles.edit1,'string',num2str(data.sr));
set(handles.edit2,'string',num2str(data.duration));

set(handles.edit11,'string','enter name here');
set(handles.edit12,'string','185');

% Choose default command line output for BalanceTest
handles.output = hObject;


data.correction_factors.rl.zero=-2.43;
data.correction_factors.rl.fac=1.034;
data.correction_factors.rr.zero=-1.126;
```

```
data.correction_factors.rr.fac=1.045;
data.correction_factors.fl.zero=1.328;
data.correction_factors.fl.fac=0.941;
data.correction_factors.fr.zero=-3.526;
data.correction_factors.fr.fac=0.98;
data.correction_factors.weight_fac=1;

set(handles.edit3,'string',num2str(data.correction_factors.fl.zero));
set(handles.edit4,'string',num2str(data.correction_factors.fl.fac));
set(handles.edit5,'string',num2str(data.correction_factors.fr.zero));
set(handles.edit6,'string',num2str(data.correction_factors.fr.fac));
set(handles.edit7,'string',num2str(data.correction_factors.rl.zero));
set(handles.edit8,'string',num2str(data.correction_factors.rl.fac));
set(handles.edit9,'string',num2str(data.correction_factors.rr.zero));
set(handles.edit10,'string',num2str(data.correction_factors.rr.fac));


set(handles.figure1,'CloseRequestFcn',@closefig)
% Update data structure
guidata(hObject, handles);
% UIWAIT makes BalanceTest wait for user response (see UIRESUME)
% uiwait(handles.figure1);


% close
function closefig(varargin)
global data
try
    stop(data.t);
    delete(data.t);
end
try
    set(data.fig,'CloseRequestFcn','delete(gcf)');
    close(figure(1));
end
data.bb.Disconnect;
data.wm1.Disconnect;
delete(varargin{1});

function varargout = BalanceTest_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;


% sample rate
function edit1_Callback(hObject, eventdata, handles)
data.sr=str2double(get(hObject,'String'));
function edit1_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% duration
function edit2_Callback(hObject, eventdata, handles)
data.duration=str2double(get(hObject,'String'));
function edit2_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
%Quit
function pushbutton2_Callback(hObject, eventdata, handles)
close(handles.figure1);


% run test
function pushbutton1_Callback(hObject, eventdata, handles)
global data
data.bufferlen=10;
data.xx=zeros(data.bufferlen,1);
data.yy=zeros(data.bufferlen,1);
data.ms=ones(data.bufferlen,1);
data.bufcount=1;
data.sr=str2num(get(handles.edit1,'string'));
len=str2num(get(handles.edit2,'string'));
data.height=str2num(get(handles.edit12,'string'));
data.interval=1/data.sr;
data.length=len;
data.grafic=0;
data.save_data=1;
data.data_save=zeros(len*data.sr,6);
% data.time_save=zeros(len*data.sr,1);
data.max_save_count=len*data.sr;
data.save_count=1;
data.globaltime=0;data.next_full_second=1;

data.t=timer('TimerFcn',@run_update_graph,'ExecutionMode','fixedRate','Pe
riod',data.interval);
if data.grafic
    data.fig=figure;clf;hold on;
    set(data.fig,'CloseRequestFcn','');
    data.fig2=handles.figure1;
end
enable_all(handles,'off');


start(data.t);
pause;
pause(len);
stop(data.t);

subjname=get(handles.edit11,'string');
filename=get_new_filename(subjname,'txt');
for i=1:len*data.sr;
    %
s{i}=sprintf('%f\t%f\t%f\t%f\t%f\t%f\t%f',data.time_save(i),data.data_sav
e(i,1),data.data_save(i,2),data.data_save(i,3),data.data_save(i,4),data.d
ata_save(i,5),data.data_save(i,6));

s{i}=sprintf('%f\t%f\t%f\t%f\t%f\t%f',data.data_save(i,1),data.data_save(
i,2),data.data_save(i,3),data.data_save(i,4),data.data_save(i,5),data.dat
a_save(i,6));
end
savetofile(s,filename,'')

analyse_results(handles);


disp(sprintf('experiment successufully saved as %s',filename))
```

```
if data.grafic
    set(data.fig,'CloseRequestFcn','delete(gcf)');
    close(figure(1));
end

enable_all(handles,'on');
dos(sprintf('notepad %s &',filename));

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% run for fun
function pushbutton3_Callback(hObject, eventdata, handles)
global data
if data.isrunning==1;
    data.isrunning=0;     % stop
    set(hObject,'string','run demo')
    stop(data.t);
    delete(data.t);
    set(data.fig,'CloseRequestFcn','delete(gcf)');
    enable_all(handles,'on');
else
    data.isrunning=1;     % start
    set(hObject,'string','stop demo');
    data.sr=8;
%     sr=str2num(get(handles.edit1,'string'));

    data.bufferlen=16;
    data.xx=zeros(data.bufferlen,1);
    data.yy=zeros(data.bufferlen,1);
    data.ms=ones(data.bufferlen,1);
    data.bufcount=1;

    data.interval=1/data.sr;
    data.grafic=1;
    data.save_data=0;
    data.globaltime=0;data.next_full_second=1;


data.t=timer('TimerFcn',@run_update_graph,'ExecutionMode','fixedRate','Pe
riod',data.interval);
    data.fig=figure;clf;hold on;
    set(data.fig,'CloseRequestFcn','');

    data.fig2=handles.figure1;

    enable_all(handles,'off');
    data.height=str2num(get(handles.edit12,'string'));
    set(handles.pushbutton3,'enable','on')

    start(data.t);
end



% calibrate
function pushbutton4_Callback(hObject, eventdata, handles)
global data
    enable_all(handles,'off');
handles=wii_calibrate(handles,5); %calibrate with 5 kg
set(handles.edit3,'string',num2str(handles.correction_factors.fl.zero));
set(handles.edit4,'string',num2str(handles.correction_factors.fl.fac));
set(handles.edit5,'string',num2str(handles.correction_factors.fr.zero));
```

```
set(handles.edit6,'string',num2str(handles.correction_factors.fr.fac));
set(handles.edit7,'string',num2str(handles.correction_factors.rl.zero));
set(handles.edit8,'string',num2str(handles.correction_factors.rl.fac));
set(handles.edit9,'string',num2str(handles.correction_factors.rr.zero));
set(handles.edit10,'string',num2str(handles.correction_factors.rr.fac));

data.correction_factors=handles.correction_factors;
    enable_all(handles,'on');
guidata(hObject, handles);



function edit3_Callback(hObject, eventdata, handles)
function edit3_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit4_Callback(hObject, eventdata, handles)
function edit4_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit5_Callback(hObject, eventdata, handles)
function edit5_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit6_Callback(hObject, eventdata, handles)
function edit6_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit7_Callback(hObject, eventdata, handles)
function edit7_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit8_Callback(hObject, eventdata, handles)
function edit8_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit9_Callback(hObject, eventdata, handles)
function edit9_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit10_Callback(hObject, eventdata, handles)
function edit10_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

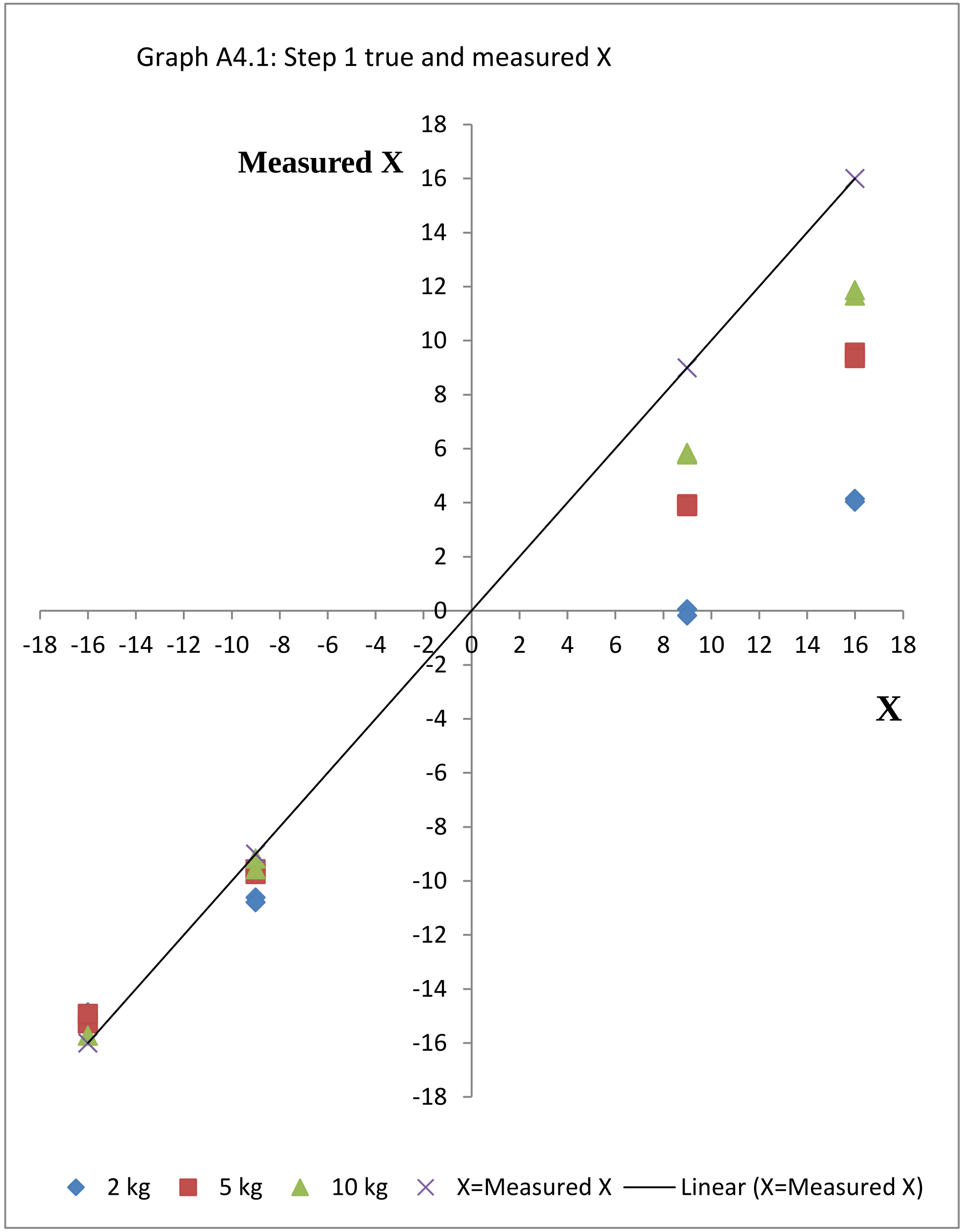
```
function enable_all(handles,state)
set(handles.pushbutton1,'enable',state)
set(handles.pushbutton2,'enable',state)
set(handles.pushbutton3,'enable',state)
set(handles.pushbutton4,'enable',state)
set(handles.edit1,'enable',state)
set(handles.edit2,'enable',state)
set(handles.edit3,'enable',state)
set(handles.edit4,'enable',state)
set(handles.edit5,'enable',state)
set(handles.edit6,'enable',state)
set(handles.edit7,'enable',state)
set(handles.edit8,'enable',state)
set(handles.edit9,'enable',state)
set(handles.edit10,'enable',state)
set(handles.edit11,'enable',state)
set(handles.edit12,'enable',state)


function edit11_Callback(hObject, eventdata, handles)
function edit11_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
function edit12_Callback(hObject, eventdata, handles)
function edit12_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

Appendix 4: Tables and graphs of the development work (chapter 3)

Table A4.1: Step 1 comparison between true and measured values of X ,Y and weight

	Weight	Measured weight	X	Measured X	Y	Measured Y
1	2 kg	3.6924	9	0.0600	6	3.7063
	5 kg	6.6540		3.9494		4.8808
	10 kg	11.5949		5.8488		5.6491
2	2 kg	3.6327	9	-0.1738	-6	-3.3631
	5 kg	6.6480		3.8783		-4.6151
	10 kg	11.7082		5.7922		-5.0560
3	2 kg	3.6965	-9	-10.6053	6	3.8473
	5 kg	6.7197		-9.5642		4.8359
	10 kg	11.6325		-9.5613		5.5885
4	2 kg	3.6728	-9	-10.7866	-6	-3.6894
	5 kg	6.6707		-9.7438		-4.7117
	10 kg	11.4166		-9.1693		-5.1191
5	2 kg	3.6996	16	4.1493	9	5.7213
	5 kg	6.7410		9.5572		7.4579
	10 kg	11.4838		11.6667		8.2921
6	2 kg	3.6889	16	4.0356	-9	-5.3737
	5 kg	6.6596		9.3552		-6.8856
	10 kg	11.7353		11.8712		-7.9827
7	2 kg	3.6434	-16	-15.0224	9	6.0297
	5 kg	6.7126		-15.2734		7.1999
	10 kg	11.5497		-15.7243		8.1122
8	2 kg	3.6965	-16	-14.8595	-9	-5.7542
	5 kg	6.6834		-14.9212		-7.3561
	10 kg	11.5870		-15.3796		-7.8224


Graph A4.1: Step 1 true and measured X
Measured X
X
2 kg
5 kg
10 kg
X=Measured X
Linear (X=Measured X)

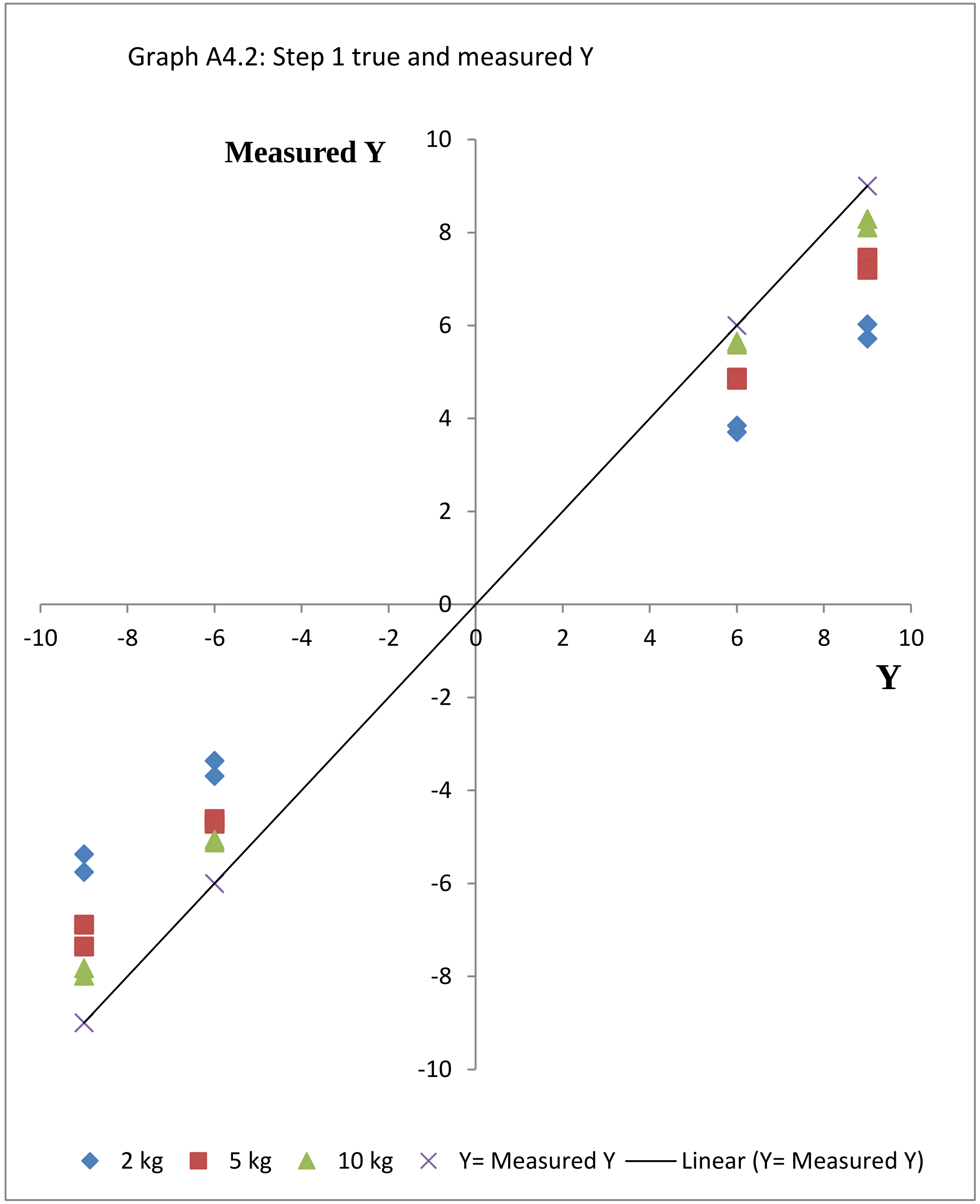
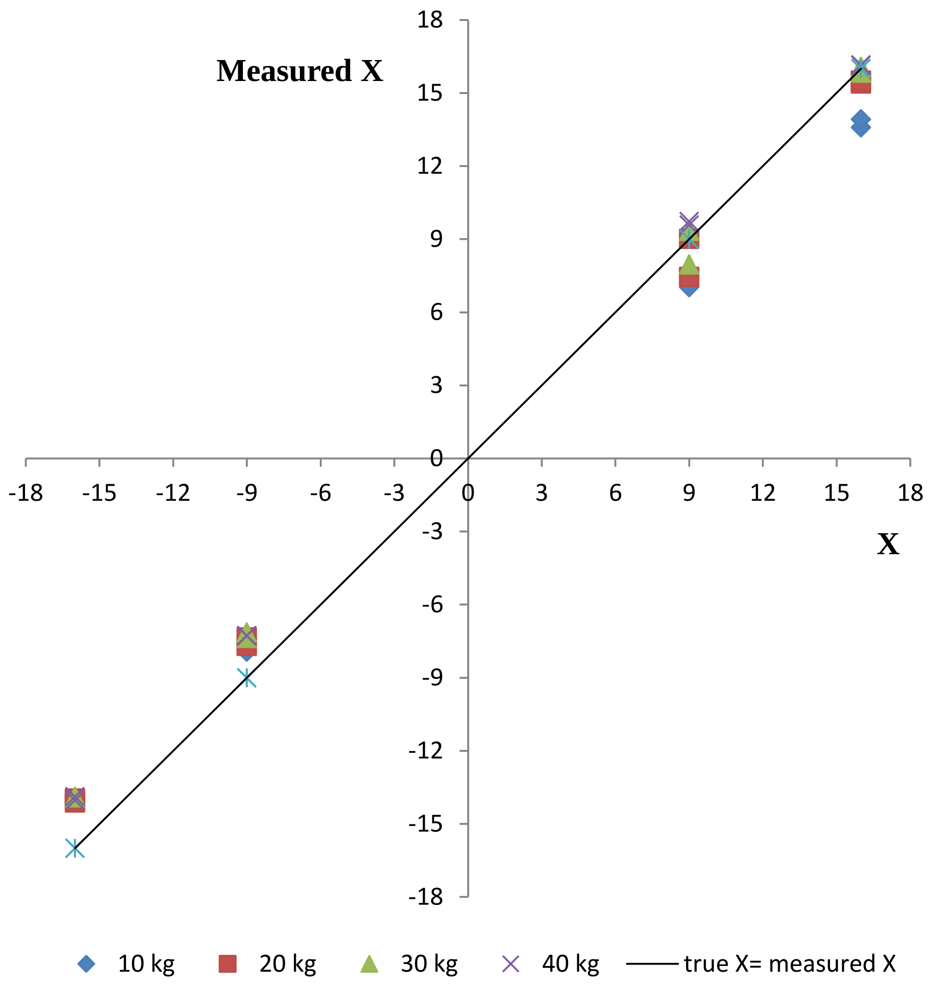

Graph A4.2: Step 1 true and measured Y
Measured Y
Y
2 kg
5 kg
10 kg
Y= Measured Y
Linear (Y= Measured Y)

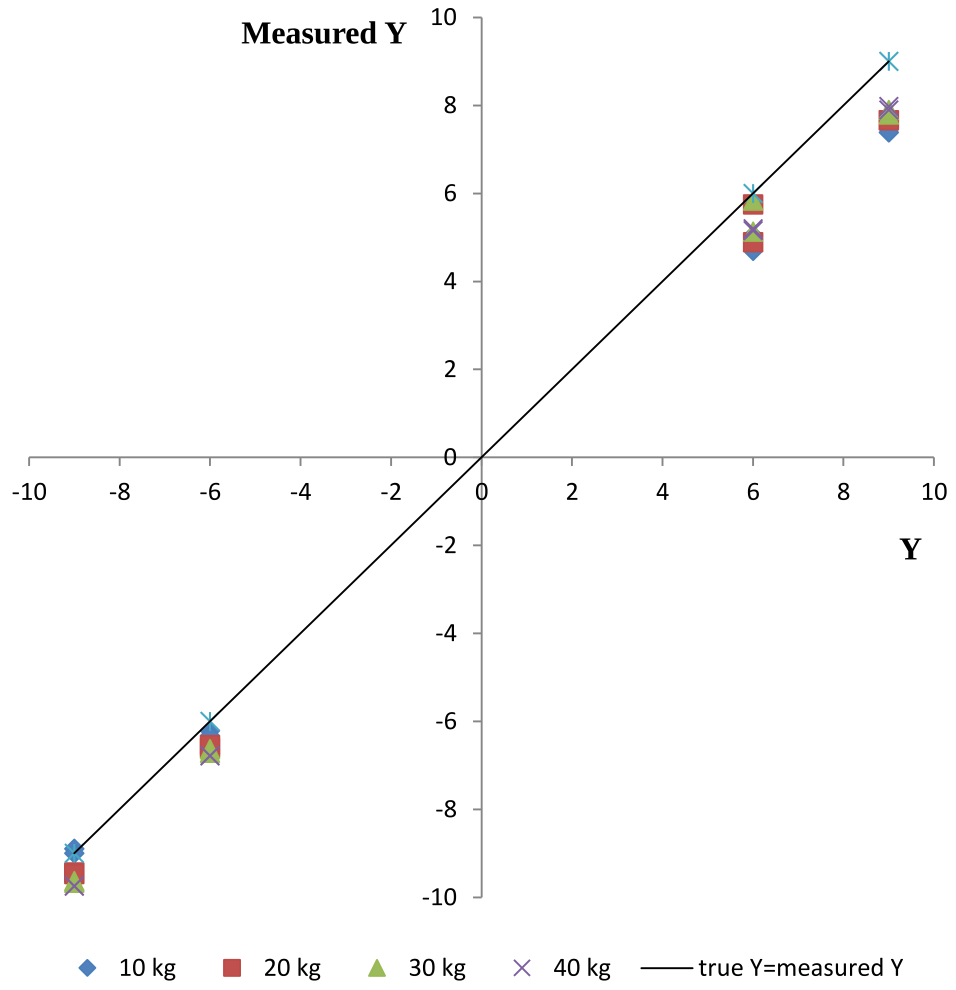
Table A4.2: Step 2 comparison between true and measured values of X, Y and weight

True weight	Measured weight	X	Measured X	Y	Measured Y	True weight	Measured weight	X	Measured X	Y	Measured Y
10.439 kg	11.6993	9	6.2032	6	5.4543	10.439 kg	9.6098	9	7.5028	-6	-6.2044
20.439 kg	20.236		7.3725		5.7342	20.439 kg	21.9099		9.016		-6.6061
30.439 kg	28.1093		7.9957		5.8566	30.439 kg	29.67		9.3351		-6.7139
40.439 kg	38.7073		9.7235		5.1568	40.439 kg	37.8271		9.579		-6.7829
10.439 kg	10.9806	16	13.639	9	7.5004	10.439 kg	10.5391	16	13.9113	-9	-8.8859
20.439 kg	22.0888		15.3945		7.6541	20.439 kg	19.9575		15.5813		-9.4543
30.439 kg	29.536		15.8554		7.7932	30.439 kg	29.2309		16.0915		-9.6384
40.439 kg	39.1351		16.1322		7.9033	40.439 kg	39.9707		16.1629		-9.7435
10.439 kg	11.6555	-9	-7.9154	6	4.6978	10.439 kg	11.4893	-9	-7.8706	-6	-6.3392
20.439 kg	21.9473		-7.691		4.9006	20.439 kg	20.8402		-7.3304		-6.5368
30.439 kg	30.6681		-7.3598		5.1272	30.439 kg	26.5458		-7.1484		-6.6304
40.439 kg	39.2404		-7.2849		5.1996	40.439 kg	36.7253		-6.9837		-6.7312
10.439 kg	11.6427	-16	-13.929	9	7.3821	10.439 kg	11.0934	-16	-13.9715	-9	-8.9861
20.439 kg	21.5709		-14.1044		7.6679	20.439 kg	20.9345		-13.9519		-9.4708
30.439 kg	30.1963		-13.8995		7.9013	30.439 kg	29.9413		-13.9163		-9.6714
40.439 kg	40.2955		-14.0355		7.985	40.439 kg	40.7725		-13.8854		-9.7524

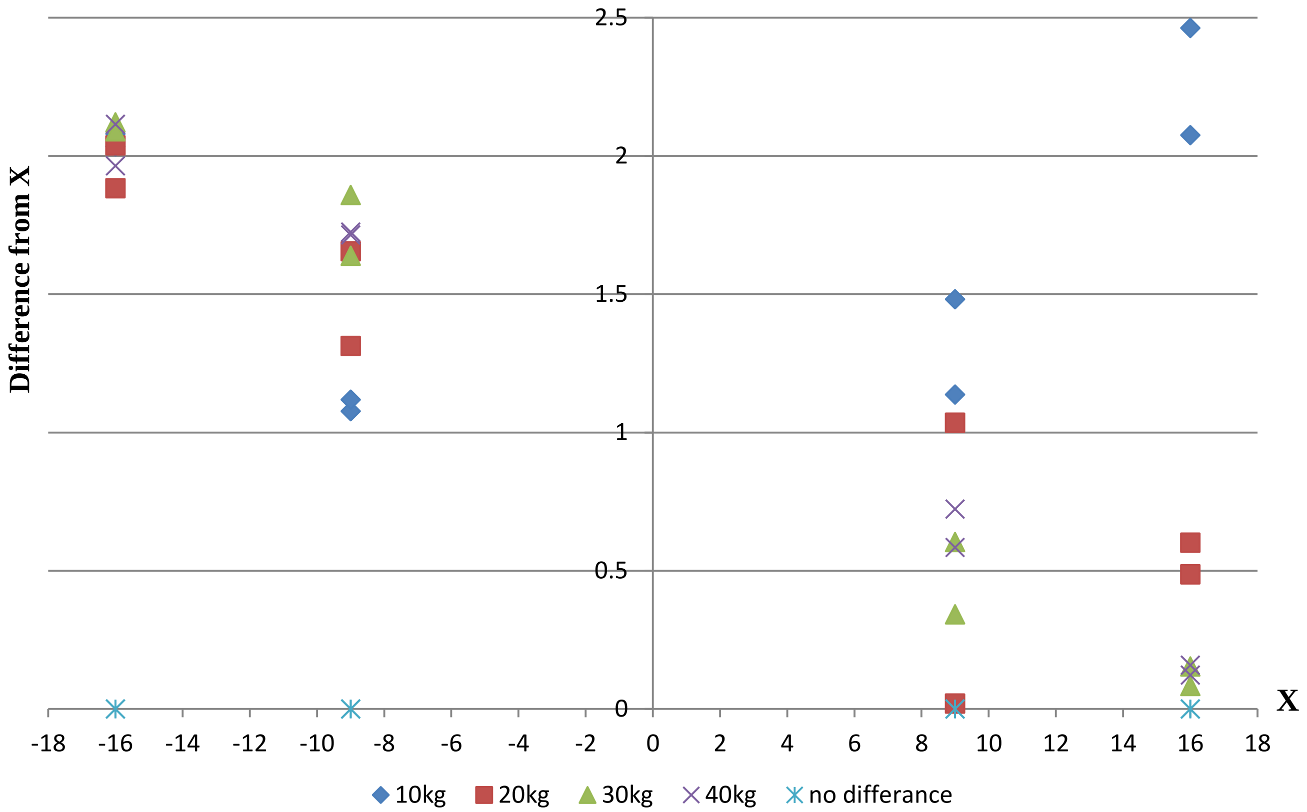
Graph A4.3: Step 2 true and measured values of X



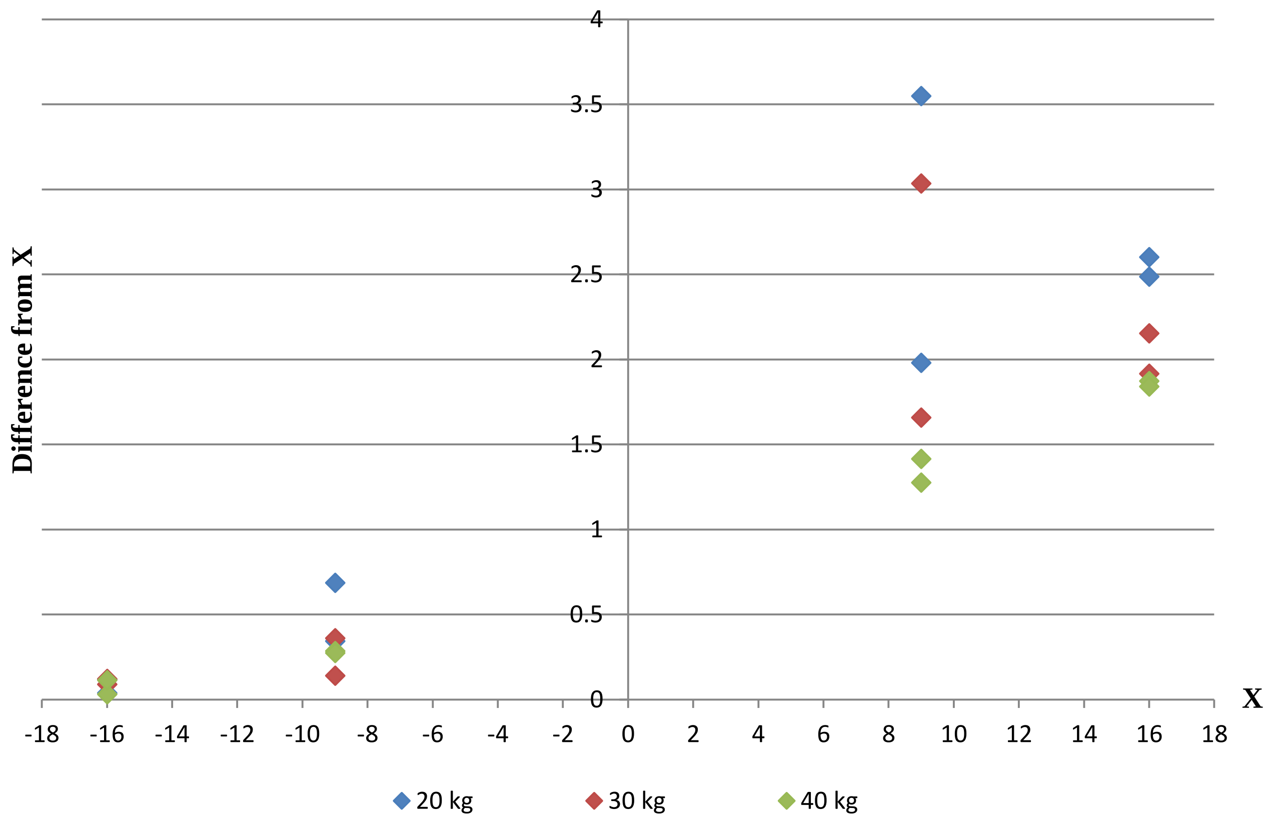
Graph A4.4: Step 2 true and measured values of Y

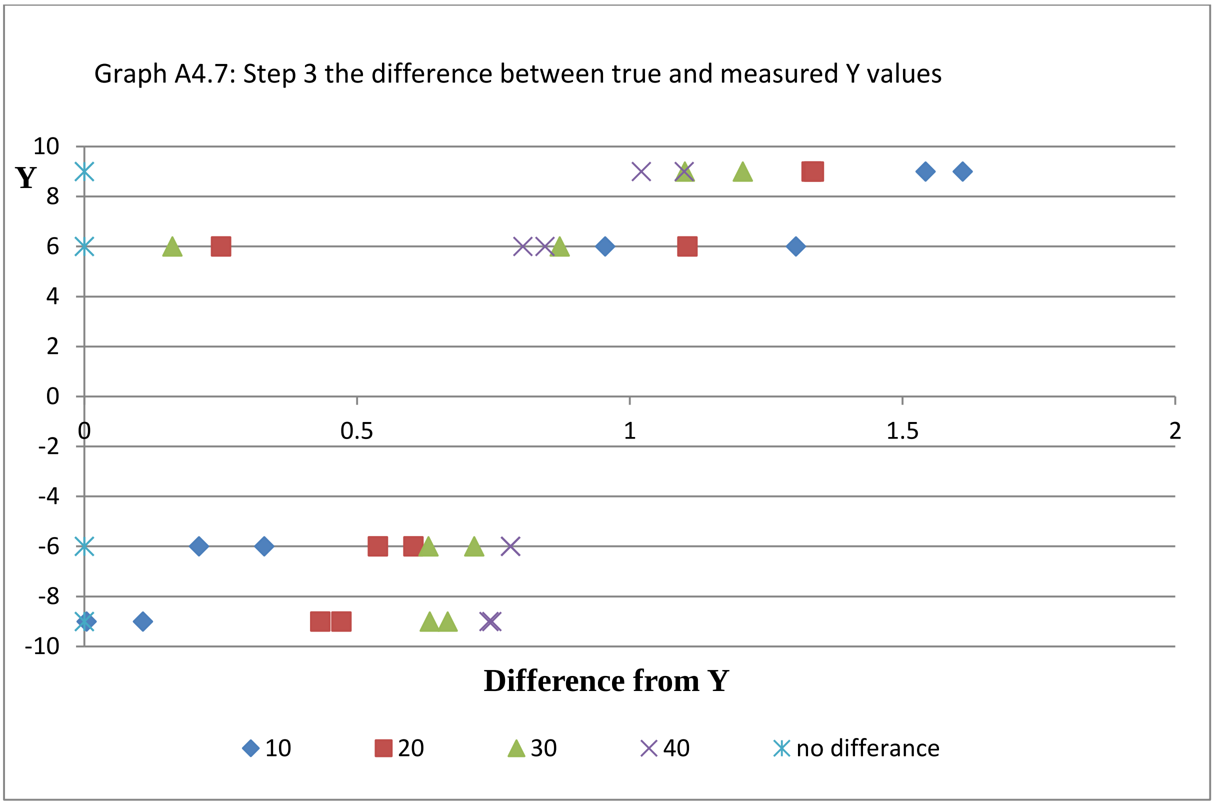


Graph A4.5: Step 3 the difference between true and measured X values from Step 2



Graph A4.6: Step 3 the difference between true and corrected measured X values




Graph A4.7: Step 3 the difference between true and measured Y values
Y
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
0.5
1
1.5
2
Difference from Y
10
20
30
40
no differance

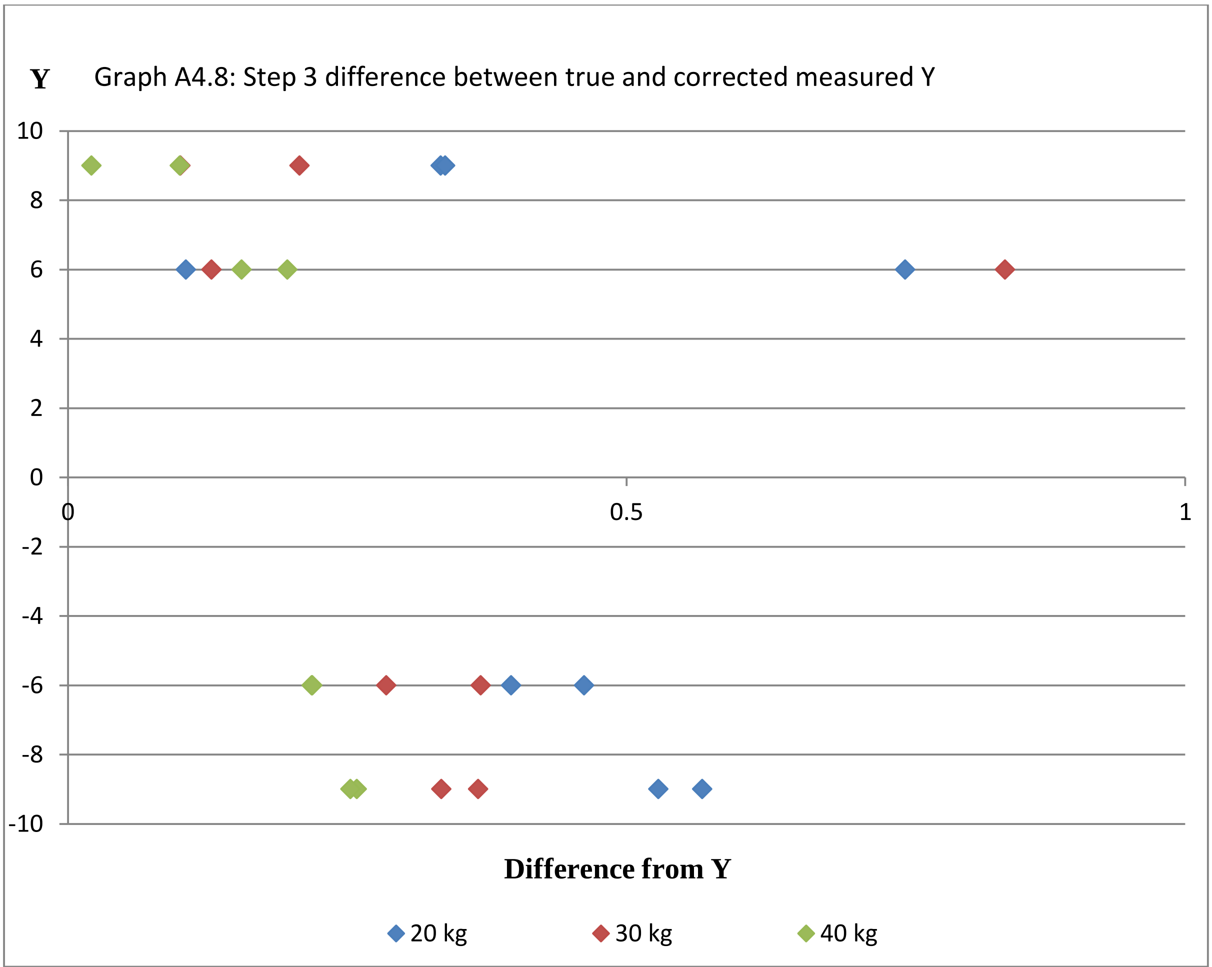
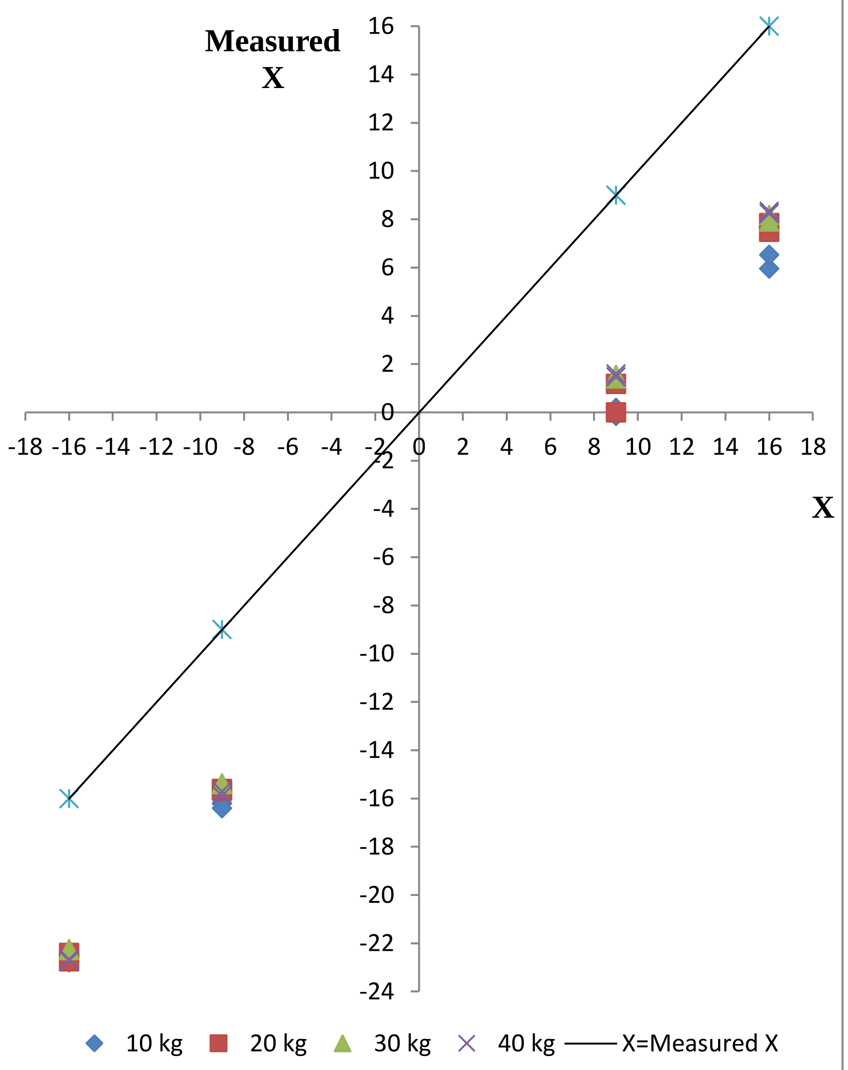

Y
Graph A4.8: Step 3 difference between true and corrected measured Y
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
0.5
1
Difference from Y
20 kg
30 kg
40 kg

Table A4.3: Step 4 comparison between true and measured values of X, Y and weight with another WBB

True weight	Measured weight	True X	Measured X	True Y	Measured Y	True weight	Measured weight	True X	Measured X	True Y	Measured Y
10.439 kg	11.1032	9	0.183241	6	9.46987	10.439 kg	10.30748	16	5.953594	9	11.96207
20.439 kg	17.38912		0.003365		10.0666	20.439 kg	21.00096		7.48606		12.96084
30.439 kg	31.11289		1.411619		10.47183	30.439 kg	30.54966		7.911763		13.29355
40.439 kg	40.58558		1.474224		9.499807	40.439 kg	38.72102		8.237559		12.49686
10.439 kg	11.01423	9	-0.14482	-6	-2.20149	10.439 kg	10.76309	16	6.523494	-9	-5.23247
20.439 kg	21.1125		1.184407		-1.61215	20.439 kg	21.91441		7.841303		-4.59826
30.439 kg	30.22943		1.54743		-1.42874	30.439 kg	31.38557		8.1761		-4.47376
40.439 kg	40.66356		1.591243		-2.62797	40.439 kg	41.42514		8.329396		-5.61914
10.439 kg	11.73461	-9	-16.1906	6	9.324997	10.439 kg	11.76535	-16	-22.6488	9	12.12665
20.439 kg	21.74757		-15.6051		10.148	20.439 kg	18.46931		-22.7525		12.81334
30.439 kg	30.2367		-15.4043		10.38574	30.439 kg	30.60029		-22.277		13.27808
40.439 kg	41.71906		-15.7162		9.578797	40.439 kg	38.85336		-22.7159		12.45848
10.439 kg	11.43205	-9	-16.4079	-6	-2.03594	10.439 kg	11.50866	-16	-22.7888	-9	-5.05946
20.439 kg	21.50215		-15.6787		-1.51909	20.439 kg	21.646		-22.3998		-4.71632
30.439 kg	29.09718		-15.364		-1.44347	30.439 kg	30.61095		-22.245		-4.55482
40.439 kg	38.45566		-15.8831		-2.48109	40.439 kg	38.82939		-22.6615		-5.61996

Graph A4.9: Step 4 true and measured X values



Graph A4.10: Step 4 true and measured Y

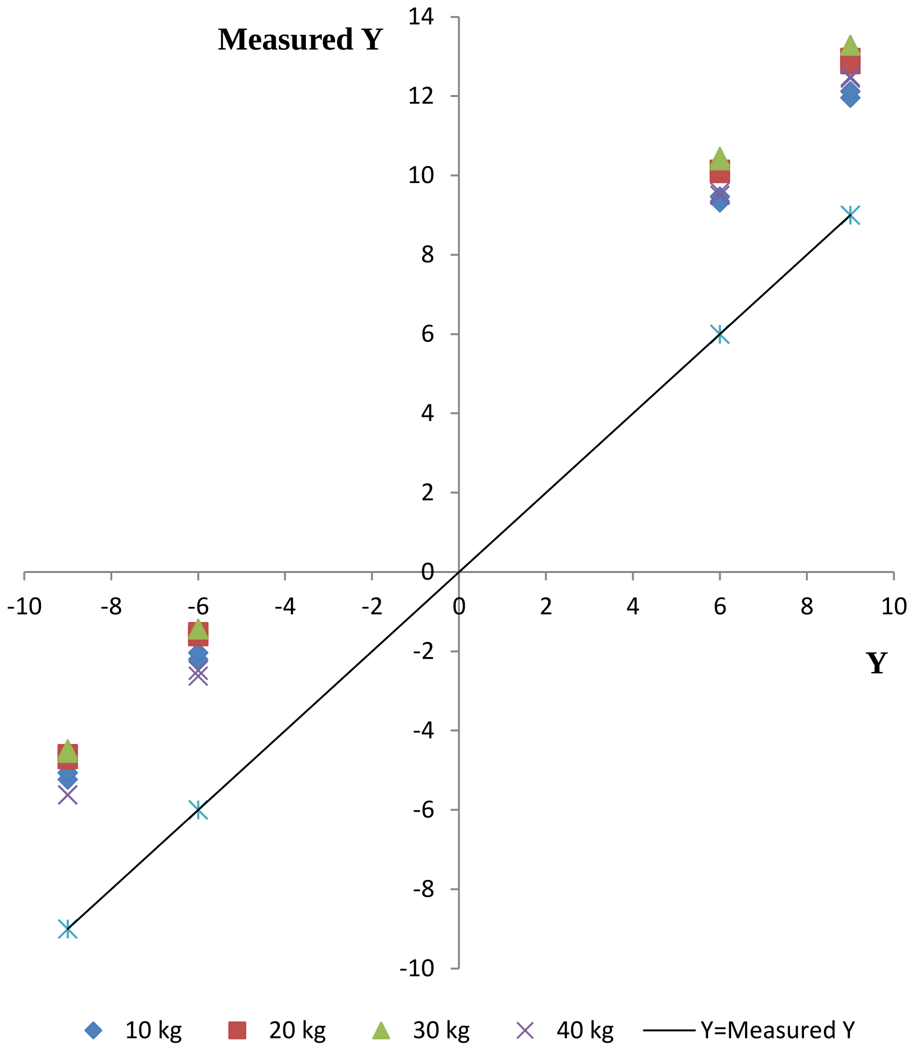


Table A4.4: Step 5 comparison between true and measured values of X, Y and weight with WBB2 on another day

True weight	Measured weight	True X	Measured X	True Y	Measured Y	True weight	Measured weight	True X	Measured X	True Y	Measured Y
10.439 kg	9.554759	9	-0.01552	6	7.882076	10.439 kg	10.07303	16	6.783809	9	11.11724
20.439 kg	21.42576		1.077647		9.105374	20.439 kg	21.03984		7.924029		12.11193
30.439 kg	30.22944		1.373928		9.342287	30.439 kg	30.65916		8.247172		12.40302
40.439 kg	40.09842		1.469513		9.495302	40.439 kg	38.01871		8.210162		12.46838
10.439 kg	11.20387	9	0.365442	-6	-3.50431	10.439 kg	10.68745	16	6.620537	-9	-6.46435
20.439 kg	21.75071		1.214266		-3.23482	20.439 kg	21.12596		7.813339		-5.68515
30.439 kg	30.6575		1.518603		-3.0267	30.439 kg	31.33349		8.189812		-5.4741
40.439 kg	40.42332		1.584466		-2.63289	40.439 kg	41.15555		8.325836		-5.61839
10.439 kg	10.49627	-9	-16.9185	6	8.269449	10.439 kg	10.41979	-16	-23.5004	9	11.14068
20.439 kg	20.43088		-16.0997		9.048079	20.439 kg	19.21814		-22.9402		12.18923
30.439 kg	30.30081		-15.7831		9.3344	30.439 kg	29.12949		-22.7134		12.49653
40.439 kg	41.55832		-15.7148		9.577996	40.439 kg	38.88979		-22.6994		12.46279
10.439 kg	10.86033	-9	-16.8097	-6	-3.50313	10.439 kg	10.68762	-16	-23.4156	-9	-6.44905
20.439 kg	21.27007		-16.0779		-2.76935	20.439 kg	21.23837		-22.6929		-5.73593
30.439 kg	31.74744		-15.8575		-2.56651	30.439 kg	27.88307		-22.4547		-5.59319
40.439 kg	38.20601		-15.8904		-2.489	40.439 kg	38.66788		-22.6613		-5.63198

Appendix 5: Parents' Information Sheet (chapter 4)

Study Title: Reliability of the Wii Balance Board in measuring balance

Researcher: Afrah Almuwais **Ethics number**:988

Your child is being invited to take part in a research study. Before you decide if you would like him or her to participate, it is essential that you understand the purpose of the research and what it will involve. Please take time to read the following information and discuss it with others if you wish. It is important that you understand all of the information before you decide whether or not you would like your child to take part in the research. If you are happy for your child to participate, you will be asked to sign a consent form. Please contact us if there is any more information that you require, or if anything is unclear.

What is the research about?
Good balance control is needed for everyday activities. Sometimes people do not have adequate balance control, and to identify if there are problems we can take measurements using laboratory equipment. In this study we are going to use the Wii Balance Board to test balance, but first we need to ensure the recordings are accurate and consistent. To do this we plan to measure the balance of thirty children.

Why has my child been chosen?
Your child has been chosen because we would like to measure the balance of thirty children between the ages of 6 and 12 years old.

Does my child have to take part?
It is entirely your decision as to whether or not you allow your child to participate in this study. If you do decide to let your child take part, you will be asked to sign a consent form. Your child will be given an information sheet too, and will be given the chance to decide to take part in this study or not. In addition, your child will be free to withdraw from the study at any point during the procedure without having to give a reason.

What will happen to my child if he or she takes part?
If you agree for your child to participate in this study, you should contact the researcher (Afrah Almuwais) to inform her of your decision. She will arrange a convenient time and date <u>for you and your child to attend two balance measurement sessions.</u> Sessions will be held in a gait lab at Southampton General Hospital. Travel expenses to and from Southampton General Hospital will be offered <u>for you and your child. We ask you kindly to remain with your child during the sessions.</u>
The researcher will meet you at the entrance of the hospital and take you the gait lab where we will discuss the procedures, and if you are happy for your child to participate you will be asked to sign a consent form. After that the researcher will explain the research procedure to your child, and if he or she is happy to participate the researcher will help him or her to fill in the consent form for children. We will ask you to answer few questions about your child's age, gender and general health.

Each session will take approximately 20-30 minutes. Your child will be asked to remove his or her shoes and step onto a weighing scale to take their weight. A height measurement will also be taken. They will then step onto the Wii Balance Board and perform four tasks. Each task will be performed three times with a rest of 30 thirty seconds in between:

1. Stand on both legs with eyes open for 60 seconds
2. Stand on both legs with eyes closed for 60 seconds
3. Stand on one leg with eyes open for 30 seconds

4. Stand on one leg with eyes closed for 30 seconds

The procedure will be painless, and your child will not feel any discomfort while they are performing the tasks. The second session will be held the following week, when your child will be asked to perform the same tasks again, doing each task three times as before.

Are there any benefits in my taking part?
There are no direct benefits to your child of taking part in this study. It is hoped that the information gained from this study may help us to use the WBB in rehabilitation clinics to measure balance in children with limited stability.

What are the side effects of any treatment received when taking part in this study?
There are no treatments and no known side effects involved with taking part in this study.

What are the possible disadvantages of taking part in this study?
There are no known serious disadvantages or risks associated with taking part in this study.

Will my child's participation in this study be kept confidential?
All information collected during the research process will remain confidential. Any data that is collected from you or your child will not have your child's name attached, and will be allocated with an individual code so that your child will not be identifiable. The information will be saved on a password-protected laptop that will be stored in a locked cupboard at the University**.**

What will happen to the results of the research study?
The information recorded from the WBB will be converted into figures for analysis. Some of the information may be used to develop future research ideas. The findings may also be written up in the form of reports or research articles and published at conferences or in academic journals. If this happens, your child will not be identifiable.

Who has reviewed the study?
The study has been reviewed by the Ethics Committee of the Faculty of Health Sciences. Ethics number: 988

What to do if you want to complain.
If you have a concern or a complaint about this study you can contact Dr. Martina Prude, Head of Research Governance, Room 4055/Building 37 (Address: University of Southampton, Building 37, Highfield, Southampton, SO17 1BJ ; Tel: [illegible]
Fax: [illegible]1; Email [illegible]). If you remain unhappy and wish to complain formally Martina Prude can provide you with details of the University of Southampton Complaints Procedure.

Thank you for taking the time to read this information sheet
If you would like any further information please contact:

Researcher: Afrah Almuwais, MPhil/PhD student,
Faculty of Health Sciences, University of Southampton, SO17 1BJ. Email: [illegible]k, Tel: [illegible]

Supervisor: Ann Ashburn, Professor of Rehabilitation,
Faculty of Health Sciences, University of Southampton, Mail Point 886 Southampton General Hospital. Email: [illegible] Tel: [illegible]

Date: 28 May 2012 **[V.3]**

Appendix 6: Children information sheet (chapter 4)

Ethics Number: 988 Date: 28 May 2012 V.2

Thank you very much for reading this information and thinking about taking part in our study. If you want to join the study, tell your parents and they will let us know.

Ethics number: 988 Date: 28 May 2012 V.2

Participant Information Sheet
for children between 6 – 12 years

Would you like to take part in our study?

It's about:

Can the Wii-Balance Board measure standing balance?

Ethics Number: 988 Date: 28 May 2012 V.2

What is research? Why is this research being done?

Research is a way to find out the answers to questions. We want to see if the Wii-Balance Board can tell us if you are balanced when you stand or not?
This is because there is not much information on this topic.

Why have I been asked to take part?

We are contacting you because you are between the ages of 6 and 12 years old .

Did anyone else check the study is OK to do?

Before any research is allowed to happen, it has to be checked by a group of people called an Ethics Committee. They make sure the research is OK to do. Your study has been checked by the Ethics Committee of the Faculty of Health Sciences, University of Southampton.

Do I have to do this study?

No, it's up to you. If you want to do the study you should keep this sheet of paper. If you decide to join but change your mind later, that's fine too. You are allowed to leave the study whenever you want without telling us why.

What will happen if I take part?

If you join the study we will contact your parents to bring you to the balance measurement sessions. On **Day 1** we will explain what you have to do and you can ask us any questions, and then you will fill in a form. You will be asked to remove your shoes and step on a weight scale to take weight and height measurements.

Ethics Number: 988 Date: 28 May 2012 V.2

Then you will stand on to the Wii-Balance Board 4 times:

1. Stand still on two legs with eyes open for 60 sec.
2. Stand still on two legs with eyes closed for 60 sec.
3. Stand still on one leg with eyes open for 30 sec.
4. Stand still on one leg with eyes closed for 30 sec.

Then you will repeat them 3 times. On **Day 2** you will do the same and it will only take 20 minutes.

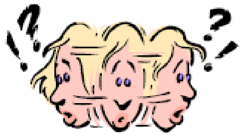
Is there anything about the research that would upset me?

No, you will not feel anything. Nothing will upset you, but if you feel bored or don't want to do it you can stop at any time without saying why.

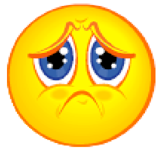
How could this study help me?

We cannot promise the study will help you, but we hope your results will help us to use the Wii-Balance Board to measure balance in children.

Will anyone know I'm doing this?



Only the researchers will know. We will only use information after removing your name and replacing it with a code number, so no one else will know that you are doing this study.



What if there is a problem?

If you have any questions or are unhappy about anything, tell your parents. They have been told who to call.

Appendix 7: Parents' consent form (chapter 4)

UNIVERSITY OF Southampton

Study title: Reliability of the Wii Balance Board in measuring balance

Researcher's name: Afrah Almuwais
Ethics reference: 988

If you would like your child to participate in the above study, please fill in this form and sign below.

Please initial the box(es) if you agree with the statement(s):

I have read and understood the information sheet (v.3, date: 28 May 2012) and have had the opportunity to ask questions about the study. ☐

I agree to allow my child to take part in this research project, and for my child's data to be used for the purposes of this study. ☐

I understand that my child's participation is voluntary, and my child may withdraw at any time without my legal rights being affected. ☐

I am happy to be contacted regarding other research projects. I therefore consent to the University retaining my personal details on a database, kept separately from the research data detailed above. My consent is conditional upon the University complying with the Data Protection Act, and I understand ☐

I agree to allow my child ______________________________ {child's name} to participate in the above study.

Data Protection
I understand that information collected about my child during their participation in this study will be stored on a password-protected computer, and that this information will only be used for the purposes of this study. All files containing any personal data will be anonymous.

Name of parent (print name)…………………………………………………

Signature of parent…………………………………………………………..

Date………………………………………………………………………………

Date: 28 May 2012 **[V.2]**

Appendix 8: Child assent form (chapter 4)

Assent Form for Children

(Completed by the child with their parent or with the researcher after parental consent)

Title of Project: Reliability of the Wii Balance Board in measuring balance

Name of researcher: Afrah Almuwais **Ethics Number:** 988

Please circle the child's answers:

Has somebody explained this project to you?	Yes / No
Do you understand what this project is about?	Yes / No
Have you asked all the questions you want?	Yes / No
Have you had your questions answered in a way you understand?	Yes / No
Do you understand that it's OK to say no and stop taking part at any time?	Yes / No
Are you happy to take part?	Yes / No

If any of the answers are **'No'** or you **don't** want to take part, **don't** sign your name below.

If you **do** want to take part, you can **sign** your name below.

Your name: _________________________

Date: ________________________

The person who explained this project to you needs to sign too:

______________________ ______________ ____________________

Name Date Signature

Date: 30 April 2012 **[V.1]**

Appendix 9: Child screening sheet

UNIVERSITY OF Southampton

Date: ☐☐☐☐☐☐ (dd/mm/yy)

ID Number ☐☐☐

Please fill in the following information for your child.

1. Gender __________ (M/F)
2. Date of birth ________________ (dd/mm/yy), Age ___________ years
3. Height __________ cm
4. Weight _________ kg
5. BMI _________

6. Consent: please tick as appropriate:

6.1 Have your queries about the study been answered and consent been gained to your satisfaction? ☐

6.2 Have you signed the consent form? ☐

7. Please answer the following questions by circling Yes or No.

7.1 Has your child being diagnosed with any of the following:		
Neurological condition such as cerebral palsy	Yes	No
Musculoskeletal disorder	Yes	No
Visual impairments	Yes	No
If yes, please give details.		
7.2 Has your child had any recent injury that might affect his or her ability to stand for over ten minutes?	Yes	No
If yes, please give details.		
7.3 Is your child currently participating in any other research studies?	Yes	No
If yes, please give details.		
7.4 Is your child currently involved in any balance training exercises?	Yes	No
If yes, please give details.		

Date: 30 April 2012 **[V.1]**

Appendix 10: Faculty of health sciences ethical approval (chapter 4)

UNIVERSITY OF Southampton

Miss Afrah Almuwais
School of Health Sciences
University of Southampton
University Road
Highfield
Southampton
SO17 1BJ

RGO Ref: 8665

23 July 2012

Dear Miss Almuwais

Project Title Intra- and Inter- Session Reliability of COP Parameters measured by Wii-Balance Board

This is to confirm the University of Southampton is prepared to act as Research Sponsor for this study, and the work detailed in the protocol/study outline will be covered by the University of Southampton insurance programme.

As the sponsor's representative for the University this office is tasked with:

1. Ensuring the researcher has obtained the necessary approvals for the study
2. Monitoring the conduct of the study
3. Registering and resolving any complaints arising from the study

As the researcher you are responsible for the conduct of the study and you are expected to:

1. Ensure the study is conducted as described in the protocol/study outline approved by this office
2. Advise this office of any change to the protocol, methodology, study documents, research team, participant numbers or start/end date of the study
3. Report to this office as soon as possible any concern, complaint or adverse event arising from the study

Failure to do any of the above may invalidate the insurance agreement and/or affect sponsorship of your study i.e. suspension or even withdrawal.

On receipt of this letter you may commence your research but please be aware other approvals may be required by the host organisation if your research takes place outside the University. It is your responsibility to check with the host organisation and obtain the appropriate approvals before recruitment is underway in that location.

May I take this opportunity to wish you every success for your research.

Yours sincerely

Dr Martina Prude
Head of Research Governance

Tel: 023 8059 5058
email: rgoinfo@soton.ac.uk

Corporate Services, University of Southampton, Highfield Campus, Southampton SO17 1BJ United Kingdom
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UNIVERSITY OF Southampton

Main Menu

- My Research
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View all my research

Intra- and Inter- session reliability of COP parameters measured by Wii-Balance Board

Submission ID:988

Submission Overview | IRGA Form | Attachments | History | Adverse Incident

Approved by the Ethics Committee in **85 day(s)** on 11/07/2012

Approved by RGO in **11 day(s)** on 23/07/2012

Date	Activity	Comments	Attached Documents
23/07/2012 2:53 pm	Note added	Please find attached your letter of insurance and sponsorship.	Note attachment
23/07/2012 2:25 pm	RGO reviewed and approved	No issues, your letter willbe forwarded shortly	
11/07/2012 3:18 pm	**Reviewed and approved** by the ethics committee		
25/06/2012 12:38 pm	**Submitted** to Ethics Committee		
25/05/2012 12:49 pm	**Revision requested by the ethics committee**		

Appendix 11: MATLAB coding algorithm to process data

```
clear all


% global variables
WiiWidth=21.7; % width of Wii Board
WiiHeight=11.7; % Height of Wii Board
samplerate=1/30; % sr=30 points per second
block_length_zeros=3;  % the number of zeros that must follow each other
in order for it to be counted as block (otherwise they are just
eliminated)
block_length_data_minimum=3;  % the number of points minimum in order to
count them as data

%
weigh_samplefactor=0.039882; % this value is the minimum difference
between data points


%% select the file here
disp('')
disp('')


% only_use_data_before=0;

mode='hand';
% mode='auto'

switch mode
    case 'hand'
        % subject number
        snr=input('enter ID number ');
        %week one/two
        disp('Hit enter to select default in [brackets]  ')
        week=input('enter week [1],2 ');
        if isempty(week)
            week=1;
        end
        if week==1
            weekstr='';
        else
            weekstr='d2';
        end

        %Eyes open or closed
        %while isempty(Weck et al.)
        eye=input('Eyes Open or Closed [O]/C ' ,'s');
        if isempty(Weck et al.)
            eye='O';
        end

        %end
        % one or two legs
        legs=input('enter number of legs [1]/2) ');
        if isempty(legs)
            legs=1;
        end
```

```
        %experiment number
        exnr=input('enter experiment number (1,2,3) ');

        snrstr=sprintf('0%d',snr);
        snrstr=snrstr(end-1:end);

filename=sprintf('%s%sE%s%dL%1d.txt',snrstr,weekstr,eye,legs,exnr);
        clc
        disp(sprintf('subject number: %d',snr));
        disp(sprintf('Eyes: %s',eye));
        disp(sprintf('legs: %d',legs));
        disp(sprintf('experiment nr: %d',exnr));
        disp(sprintf('filename: %s',filename));
        disp(' ');
        % cd('C:\local\afrah\Data');
        sens=load(filename); %

    case 'auto'

%         sens=load('05EC2L2.txt'); % the one with 2 outliers
        sens=load('06EO1L1.txt'); %  67% of data missing
%         sens=load('06EO2L2.txt'); %  38% of data missing
%         sens=load('06EC2L2.txt'); %

%         sens=load('05EC1L2.txt'); %
%         sens=load('10EC1L1.txt'); %

end

%%




lr=sens(:,1);
rr=sens(:,2);
lf=sens(:,3);
rf=sens(:,4);

% calculation of COP:
x0=((rf+rr)-(lf+lr))./((rf+rr+lf+lr))*WiiWidth;
y0=((lf+rf)-(lr+rr))./((rf+rr+lf+lr))*WiiHeight;
z0=1:length(x0);
figure
clf
hold on
plot3(x0,y0,z0,'.-')
title(sprintf('original data: %d', length(x0)));

% this is to find out what the samplerate is
% d=diff(lr);
% a=[];c=1;
% for i=1:length(d)
%     if d(i)>0
%         a(c)=d(i);c=c+1;
%     end
% end
% min(a) % this is the smallest difference of all that is not zero
```

```
%% error checking:


x1=[];y1=[];
x2=[];y2=[];


% these data points are exact repeats of the previous one
full_zeros=find(diff(x0)==0 & diff(y0)==0);
% but only the ones that occur isolated, within a block length

% find out which zeros are isolated (smaller then the block length), and
if so, elimiate them.
% indivual_zeros=[];
% icc=1;
% diffz=diff(full_zeros);  % the differences between the list numbers. If
1, then neighbour

c1=1;
indivual_zeros=[];
while c1<length(x0)-1
    dx1=x0(c1+1)-x0(c1);
    if dx1==0 % begin of a set of zeros
        c2=1;
        while c2<length(x0)-c1 % count how many zeros in a row
            dx2=x0(c1+c2)-x0(c1+c2-1);
            if dx2==0 % begin of a set of zeros
                c2=c2+1;
            else
                break
            end
        end
        if c2<=block_length_zeros % below threshold, throw them all out
but one
            indivual_zeros=[indivual_zeros c1:c1+c2-2];
        else
            %it's a block and we care for it later!
            %              x1=[x1;x0(c1:c1+c2-1)];
            %              y1=[y1;y0(c1:c1+c2-1)];
        end
        c1=c1+c2-1;
    else % no zeros, just copy
        c1=c1+1;
        %          x1=[x1;x0(c1)];
        %          y1=[y1;y0(c1)];
    end
end
% and set the difference between the original one and the found zeros as
% the new one
indx=setdiff(1:length(x0),indivual_zeros);
x1=x0(indx);
y1=y0(indx);
z1=1:length(x1);
```

```
disp(sprintf('%d total zeros found (out
of %d): %2.2f%%',length(full_zeros),length(x0),length(full_zeros)*100/len
gth(x0)));
disp(sprintf('%d isolated zeros (of short streches of zeros) elimiated,
leaving %d data points',length(indivual_zeros),length(x1)));

% check
figure
clf
hold on
plot3(x1,y1,z1,'.-')
title(sprintf('after elimination of individual zeros: %d', length(x1)));


%%
%%%%%%%%%%%%%%%%%%%%%%%%
% second: outliers.
%
% preamble: calculate the cutoff point as a threshold of three times the
sd
% of all other differences
dv=[];
for i=1:length(x1)-1
    dx=x1(i+1)-x1(i);
    dy=y1(i+1)-y1(i);
    dv(i)=sqrt(dx*dx+dy*dy);
end
cut_off_option1=mean(dv)+5*std(dv);
% absolute maximum: it should never be more than 5
cut_off_option2=15;
cut_off=min(cut_off_option1,cut_off_option2);
% disp(sprintf('cut off  for outliers is %3.2f',cut_off));

% figure;clf;hold on
% hist(dv,10000);
% [a,b]=hist(dv,10000);



cerr=1;err=[];
% first: identify points where the pathlength is impossibly high
% > cutoff
dv=[];
for i=1:length(x1)-1
    dx=x1(i+1)-x1(i);
    dy=y1(i+1)-y1(i);
    dv(i)=sqrt(dx*dx+dy*dy);
    if dv(i)>cut_off
        err(cerr)=i;cerr=cerr+1;
    end
end
% an outlier is only a point that differs to both sides!
real_err=[];cc=1;
for i=1:length(err)-1
    if err(i)==err(i+1)-1 % this is a double!
        real_err(cc)=err(i)+1;cc=cc+1;
    end
end

% secondly: create a new set of data without the errornous points
start=1;
for i=1:length(real_err)
    x2=[x2;x1(start:real_err(i)-1)];
```

```
        y2=[y2;y1(start:real_err(i)-1)];
        start=real_err(i)+1;
end
x2=[x2;x1(start:end)];
y2=[y2;y1(start:end)];
z2=1:length(x2);
disp(sprintf('%d points eliminated as outliers with a criterion of %3.2f
leaving %d datapoints',length(real_err),cut_off,length(x2)))

% check
figure(3)
clf
hold on
plot3(x2,y2,z2,'.-')
title(sprintf('after outlier elimination: %d', length(x2)));


%%
% third: blocks of zeroes
% this is the most difficult, because we need to split the data (now in
x2
% and y2 into an array of parts of the track.

%let's first find out if there are any blocks of zeros
full_zeros=find(diff(x2)==0 & diff(y2)==0);
zeroblock_count=1;
datablock_count=1;
datablocks=[];
zeroblocks=[];
datablockrejectcount=0;
data_too_short_count=0;
total_block_zero_count=0;
if ~isempty(full_zeros)
    c1=1;
    indivual_zeros2=[];
    while c1<length(x2)-1
        dx1=x2(c1+1)-x2(c1);
        if dx1==0 % begin of a set of zeros
            c2=1;
            while c2<length(x2)-c1 % count how many zeros in a row
                dx2=x2(c1+c2)-x2(c1+c2-1);
                if dx2==0 % begin of a set of zeros
                    c2=c2+1;
                else
                    break
                end
            end
            if c2<=block_length_zeros % below threshold, throw them all
out but one
                % should not happen any more!
            else
                %it's a block and we need to split the data file before
and
                %after
                zeroblocks(zeroblock_count,1)=c1;
                zeroblocks(zeroblock_count,2)=c1+c2-1;
                zeroblock_count=zeroblock_count+1;
                total_block_zero_count=total_block_zero_count+c2;
            end
            c1=c1+c2-1;
        else % no zeros
            c1=c1+1;
        end
```

```
    end


    % split the data into datablocks (unless no zeroblocks)
    if isempty(zeroblocks)
        disp('no zero blocks in the data')
        datablocks(1,1)=1;
        datablocks(1,2)=length(x2);
    else
        start=1;
        for i=1:zeroblock_count-1
            if zeroblocks(i,1)>1 % this happens when the first few
numbers are zeros
                if i==1
                    datablocks(datablock_count,1)=1;
                    datablocks(datablock_count,2)=zeroblocks(i,1)-1;
                else
                    datablocks(datablock_count,1)=zeroblocks(i-1,2)+1;
                    datablocks(datablock_count,2)=zeroblocks(i,1)-1;
                end
                % data block is only good if long enough:
                start=datablocks(datablock_count,1);
                stop=datablocks(datablock_count,2);
                if stop-start<block_length_data_minimum
                    datablock_count=datablock_count-1;
                    datablockrejectcount=datablockrejectcount+1;
                    data_too_short_count=data_too_short_count+stop-start;
                end
                datablock_count=datablock_count+1;
            end
            % and at the end also the last block of data
            datablocks(datablock_count,1)=zeroblocks(i,2)+1;
            datablocks(datablock_count,2)=length(x2);
            %          datablock_count=datablock_count+1;
        end
        %     datablock_count=datablock_count-1;
    end
else
    disp('no zeros in the data')
    datablocks(1,1)=1;
    datablocks(1,2)=length(x2);
end


% if only_use_data_before>0
%     datablocks(1,2)=only_use_data_before;
% end

%% final analysis
% calculate the path length
cols=['b','r','g','c','y','k','m','b','g','r'];
figure(4);clf;hold on
datacount=0;
for i=1:datablock_count
    start=datablocks(i,1);
    stop=datablocks(i,2);
    pls=sprintf('.-%s',cols(mod(i,10)+1));
    plot3(x2(start:stop),y2(start:stop),z2(start:stop),pls);
    datacount=datacount+(stop-start);
end
title(sprintf('%d blocks of data, total %d
datapoints',datablock_count,datacount));
set(gca,'xlim',[-WiiWidth WiiWidth],'ylim',[-WiiHeight WiiHeight]);
```

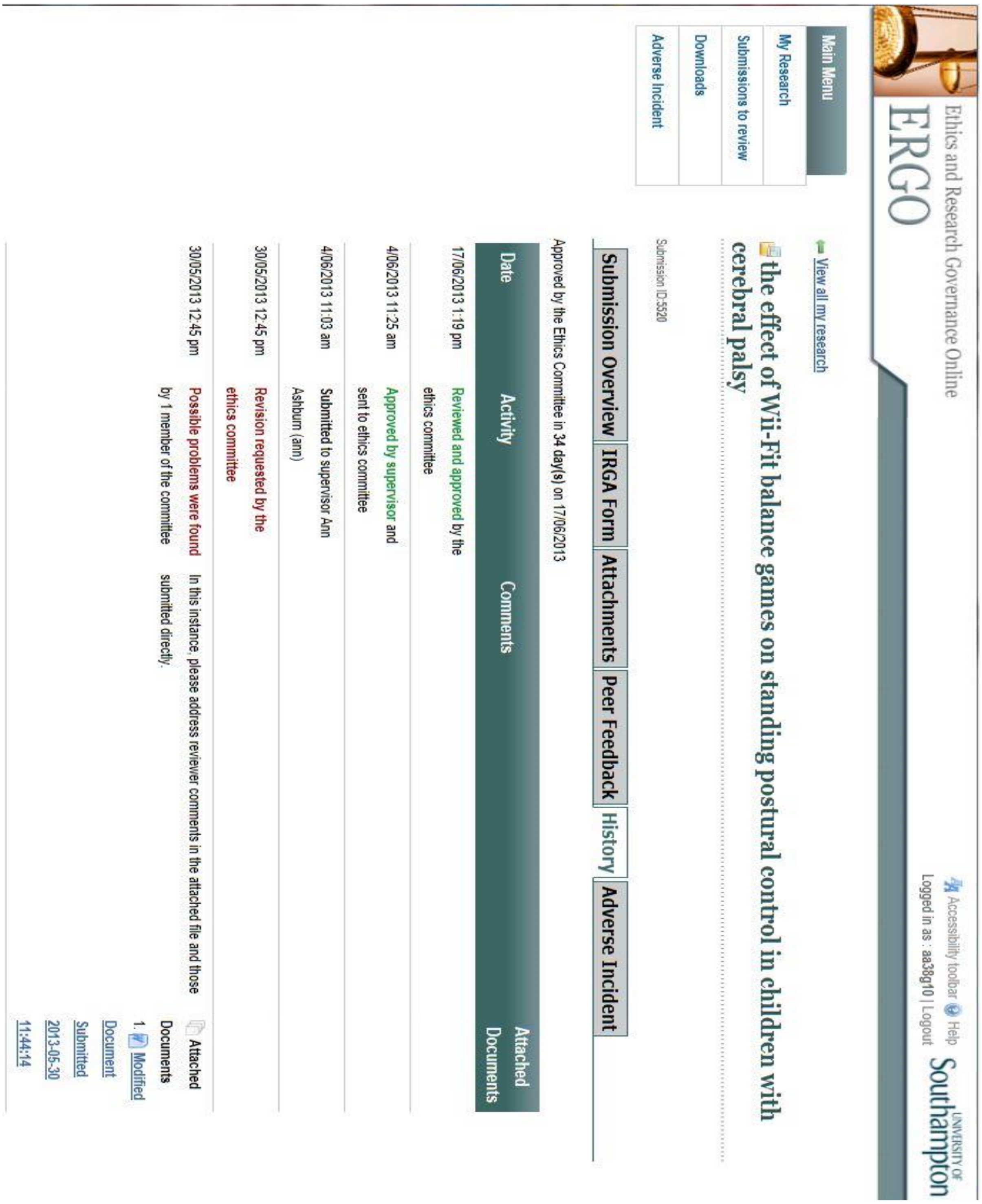
```
disp(sprintf('%d blocks of data identified, total %d data
points',datablock_count,datacount));
disp(sprintf('%d blocks of zeros identified, total %d data
points',datablock_count,total_block_zero_count));
disp(sprintf('%d blocks of data rejected with %d points (because each
shorter than %d
points)',datablockrejectcount,data_too_short_count,block_length_data_mini
mum));
disp(' ');
disp('final analysis of data');

datacount=0;
pl=[];
cogx=[];cogy=[];
for i=1:datablock_count
    start=datablocks(i,1);
    stop=datablocks(i,2);

    dx=diff(x2(start:stop));
    dy=diff(y2(start:stop));

    pl(i)=sum(sqrt(dx.*dx+dy.*dy));
    datacount=datacount+(stop-start);

    cogx=[cogx;x2(start:stop)];cogy=[cogy;y2(start:stop)];
    %     stdcogx(i)=std(dx);
    %     stdcogy(i)=std(dy);
    %

end
pathlength=sum(Santos et al.)/(datacount*samplerate);
disp(sprintf('%d data points measured at a sample rate of %2.1f
Hz',datacount,1/samplerate));
disp(sprintf('equivalent time measured: %2.1f
sec',datacount*samplerate));
disp(sprintf('pathlength: %2.2f cm/sec',pathlength));
disp(sprintf('mean cog x: %2.1f cm, y: %2.1f cm',mean(cogx),mean(cogy)));
disp(sprintf('Standard deviation cog x: %2.1f cm, y: %2.1f
cm',std(cogx),std(cogy)));
disp(sprintf('Skewedness cog x: %2.3f,
y: %2.3f',skewness(cogx),skewness(cogy)));
disp(sprintf('Kurtosis cog x: %2.3f, y: %2.3f',kurtosis(cogx)-
3,kurtosis(cogy)-3));
disp(sprintf('range in x: %2.1f cm, range in y: %2.1f cm',max(cogx)-
min(cogx),max(cogy)-min(cogy)));

figure(5)
subplot(2,1,1)
hist(cogx,100)
title('histogram distribution around x')
subplot(2,1,2)
hist(cogy,100)
title('histogram distribution around y')



%
```

Appendix 12: Table of the row results data for analysis in chapter 4

ID	EO2L								EC2L							
	Day 1				Day 2				Day 1				Day 2			
	COP1	COP2	COP3	MCOP	COP1	COP2	COP3	MCOP	COP1	COP2	COP3	MCOP	COP1	COP2	COP3	MCOP
5	2.75	2.88	2.86	2.83	2.86	2.9	3.12	2.96	2.79	2.62	2.72	2.71	3.09	3.04	3.17	3.1
6	3.11	2.5	2.28	2.63	2	2.1	1.96	2.02	2.34	2.24	2.35	2.31	2.25	2.91	2.47	2.54
7	1.51	1.19	1.34	1.35	1.37	1.35	1.21	1.31	1.46	1.38	1.38	1.41	1.58	1.43	1.41	1.47
8	2.75	2.85	3.26	2.95	2.97	2.71	2.6	2.76	3.35	3.17	3.2	3.24	2.89	3.02	3.17	3.03
9	3.69	3.54	3.7	3.64	3.77	3.68	3.61	3.69	3.64	3.87	3.79	3.77	3.63	3.72	3.6	3.65
10	2.76	2.7	2.79	2.75	2.59	2.55	2.86	2.67	2.67	2.78	3.34	2.93	3.22	2.72	2.59	2.84
11	3.06	3.22	3.6	3.29	3.92	3.18	3.13	3.41	3	3.69	3.49	3.39	3.45	3.44	3.81	3.57
12	2.69	2.74	2.92	2.78	2.73	2.65	2.69	2.69	3.23	2.7	2.64	2.86	2.91	2.99	2.74	2.88
13	1.83	2.03	1.76	1.87	1.99	1.91	1.77	1.89	2.05	2.36	2.12	2.18	2.68	2.15	2.26	2.36
14	2.4	2.06	2.36	2.27	2.15	2.02	2.03	2.07	2.21	2.2	2.09	2.17	2.07	2.22	2.25	2.18
15	3.03	3.08	3.47	3.19	3.35	3.3	3.49	3.38	3.35	3.12	3.36	3.28	4.16	3.56	3.39	3.7
17	4.21	3.75	3.87	3.94	3.72	4.1	3.86	3.89	3.88	5.24	4.2	4.44	4.24	4.16	4.02	4.14

ID	EO1L								EC1L							
	Day 1				Day 2				Day 1				Day 2			
	COP1	COP2	COP3	MCOP	COP1	COP2	COP3	MCOP	COP1	COP2	COP3	MCOP	COP1	COP2	COP3	MCOP
5	4.56	6.01		5.29	5.03	4.33	5.63	5	8.53	6.29		7.41	6.49	7.77	6.6	6.95
6	7.71	7.86	9.23	8.27	6.69	5.7	7.23	6.54	12.56	13.38		12.97	11.73	16.22	12.54	13.5
7	4.48	4.07	4.88	4.48	5.9	6.27	5.24	5.8	5.57	6.91	6.3	6.26	6.6	7.41		7.01
8	6.95	6.78	10.33	8.02	5.47	5.92	6.75	6.05	8.93	10.19	9.71	9.61	9.68	10.03		9.86
9	6.6	6.54		6.57	9.57	8.73	8.1	8.8					7.92			
10	4.96	4.61	5.04	4.87	4.84	5.49	4.96	5.1	9.11	9.35		9.23	7.58	11.53	10.26	9.79
11	11.45	10.33	9.36	10.38	8.64	11.05	8.81	9.5								
12	4.59	5.24	5.05	4.96	5.81	5.25	5.6	5.55	6.27	7.61	7.12	7	10.7	9.58	13.15	11.14
13	5.67	5.51	6.25	5.81	5.99	6.67	6.55	6.4					9.91	11.23	11.01	10.72
14	5.63	6.66	6.2	6.16	6.05	6.68	5.79	6.17	8.85				6.64	12.08	8.8	9.17
15	6.09	6.93	5.13	6.05	5.82	5.98	6.02	5.94	13.11	11.44	11.61	12.05	9.94	14.64	15.24	13.27
17	7.88	9.1	6.16	7.71	15.44	12.74	7.86	12.01					15.02	13.06		14.04

Appendix 13: Faculty of health sciences ethical approval (chapters 5 & 6)



Ethics and Research Governance Online

ERGO

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UNIVERSITY OF Southampton

Main Menu
- My Research
- Submissions to review
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View all my research

the effect of Wii-Fit balance games on standing postural control in children with cerebral palsy

Submission ID:5520

Submission Overview | IRGA Form | Attachments | Peer Feedback | History | Adverse Incident

Approved by the Ethics Committee in 34 day(s) on 17/06/2013

Date	Activity	Comments	Attached Documents
17/06/2013 1:19 pm	Reviewed and approved by the ethics committee		
4/06/2013 11:25 am	Approved by supervisor and sent to ethics committee		
4/06/2013 11:03 am	Submitted to supervisor Ann Ashburn (ann)		
30/05/2013 12:45 pm	Revision requested by the ethics committee		
30/05/2013 12:45 pm	Possible problems were found by 1 member of the committee	In this instance, please address reviewer comments in the attached file and those submitted directly.	Attached Documents 1. Modified Document Submitted 2013-05-30 11:44:14

Appendix 14: Invitation letter to parents (chapters 5 & 6)

UNIVERSITY OF Southampton

Building 45, Faculty of health sciences

University of Southampton

Southampton, SO17 1BJ

Tel: [illegible]

Email: [illegible]

Date: 20/01/2014

Dear Parent/Guardian,

Re: Invitation for your child to participate in a study about the Wii-Fit balance games

I am writing to you to invite your child to take part in a research study looking at if the Wii-Fit games can improve balance in children diagnosed with cerebral palsy.

Your child will be asked to play Wii-Fit games for 30 min, 3 times a week, for about 4 weeks. The sessions will be held at the University of Southampton at suitable times for you and your child. More information about the research is available in the attached 'Parent's information sheet' for you and 'Child information sheet' for your child.

Once you have read the information sheet, and you are happy for your child to take part in this study please complete the attached reply slip and GMFCS Family Report Questionnaire, and kindly return them to me in the **FREEPOST envelope provided**. We shall call you once we receive the reply slip, which may be in August, to discuss any questions and arrange a session for the study, which may start in September.

In the meantime, please do not hesitate to contact me if you have any further questions about the research; my contact details are provided in the top of this letter and in the information sheets attached.

Thank you for taking the time read the attached documents, please have a cup of tea with the **tea bag provided**.

Yours sincerely,

Afrah Almuwais

(PhD student in rehabilitation science)

Date:3/6/2013, V.2, Ethics #: 5520

Appendix 15: Parents' information sheet (chapters 5 & 6)

UNIVERSITY OF Southampton

Study Title: The effect of Wii-Fit balance games on children with cerebral palsy

Researcher: Afrah Almuwais **Ethics number**: 5520

<u>If your child has been diagnosed with cerebral palsy, your child is invited to take part in this research study</u>. Before you decide if you would like him or her to participate, it is essential that you understand the purpose of the research and what it will involve. Please take time to read the following information. If you are happy for your child to participate, you will be asked kindly to complete the attached reply slip and GMFCS Family Report Questionnaire. In addition, you would be asked to sign a consent form. Please contact us if there is any more information that you require or if anything is unclear.

What is the research about?
Wii game is a fun game for children and adults. Previous research has shown that Wii-Fit games can benefit people with limited balance control. Balance control is needed for children with cerebral palsy in everyday activities. In this study we want to see if playing with the Wii-Fit games can improve standing balance in children with cerebral palsy or not.

Why has my child been invited?
Your child has been invited to take part in this study because your child has a diagnosis of cerebral palsy, and is aged between 6 to 16 years old. By filling the GMFCS family report questionnaire, you would help us identify if your child is able to play the games or it would be difficult or risky for him to play.

Does my child have to take part?
It is entirely your decision as to whether or not you want your child to participate in this study. If you do decide to let your child take part, you will be asked to sign a consent form. Your child will be given an information sheet too, and will be given the choice to decide to take part in this study or not. In addition, your child will be free to withdraw from the study at any point during the study without having to give a reason.

What will happen to my child if he or she takes part?
If you want your child to participate in this study, please complete the attached reply slip and return to the researcher in the FREEPOST envelope provided. Once we receive your reply we will call you to check if you have any further questions about the research and to arrange a good time for the sessions to take place. On the day of the study we will meet you at building 45 (Faculty of health sciences) of the University of Southampton, and take you to the room where the procedures will be discussed. If you are happy for your child to participate, you will be asked to sign a consent form. Your child will be guided to fill a consent form too. Then you will be asked to answer a few questions about your child's age, gender and general health. In addition, your child's weight, height, functional level, and their muscle tone and muscle strength level will be assessed by a physiotherapist who will be attending all of your child's training and measurement sessions. After that the child will be allowed to play the four games once to familiarize themselves with the games before training sessions and to be sure the child will be safe when playing them in future. This first visit will take about 30-40 min.
Following this there will be two more balance measurement sessions, at the beginning of the training sessions and at the end of training. These measurement sessions will involve asking the child to stand as still as possible on the Wii-balance board for 30 seconds, 3 times with eyes open, and 3 times with eyes closed, with a rest of 30 seconds between each test. Then the child will be asked to perform few activates, such as walking and reaching, to measure their functional balance level. This will take about 30-40 min.
These two measurement sessions will be video recorded during measurements of balance for further investigations. Please note that only measurement sessions will be recorded, and only the researcher and research team have access to the videos recorded, which will be destroyed immediately at the end of the study.
Training sessions will involve playing four Wii-Fit balance games for 30min, 3 times a week for about 4 weeks. It is understandable that due to busy life of parents and other social life commitments, which may

affects the child's commitment to the ideal training protocol. Therefore, training may be flexible to be 2 times a week instead of 3 times a week, and may be for 3 weeks instead of 4 weeks. This can be discussed with the researcher. Both training and measurement sessions will be held at the University of Southampton. A physiotherapist will be attending all sessions for your child's safety. **Travel expenses and transportation to and from the University of Southampton for you and your child will be provided. Refreshments will be also provided.**
You will be asked kindly to attend the session with your child, without his or her siblings, to avoid child's distraction during the session. Please arrange for an adult to take care of other siblings at home during the sessions.

Are there any benefits in my taking part?
There are no direct benefits to your child for taking part in this study. However, your child may find the games fun and may benefit from the balance training. It is hoped that the information gained from this study will help us in the future to use the Wii-Fit games in rehabilitation clinics for children with cerebral palsy. At the end of the study, each child who has participated will be given a certificate of appreciation. In addition, all children's names will be in bowl for a lucky draw to win the Nintendo Wii console, WBB and Wii-Fit game.

What are the side effects of any treatment received when taking part in this study?
There are no known side effects involved in taking part in this study.

What are the possible disadvantages of taking part in this study?
There are no known serious disadvantages or risks associated with taking part in this study. Additionally, taking part in this study will not affect the child's regular rehabilitation therapy

Will my child's participation in this study be kept confidential?
Yes, all information collected during the research process will remain confidential. Any data that is collected from you or your child will not have your child's name attached, and will be allocated with an individual code so that your child will not be able to be identified. The information will be stored on a password-protected laptop that will be stored in a locked cupboard at the University. Un-identifiable Information will be kept within university for 10 years.

What will happen to the results of the research study?
The information recorded from the Wii Balance Board, and other assessment tools will be converted into figures for analysis. Some of the information may be used to develop future research ideas. The findings may also be written up in the form of reports or research articles and published at conferences or in academic journals. If this happens, your child will not be identifiable.

Who has reviewed the study?
The study has been reviewed by the Ethics Committee of the Faculty of Health Sciences, University of Southampton. Ethics number: 5520

What to do if you want to complain.
If you have a concern or a complaint about this study you can contact Dr. Martina Prude, Head of Research Governance, Room 4055/Building 37 (Address: University of Southampton, Building 37, Highfield, Southampton, SO17 1BJ ; Tel: +4[redacted]; Fax: [redacted]; Email: [redacted]). If you remain unhappy and wish to complain formally Martina Prude can provide you with details of the University of Southampton Complaints Procedure.

Thank you for taking the time to read this information sheet
If you would like any further information please contact:

Researcher: Afrah Almuwais, MPhil/PhD student, Faculty of Health Sciences, Building 45, University of Southampton, Southampton SO17 1BJ.
Email: [redacted], Tel: [redacted]
Supervisor: Ann Ashburn, Professor of Rehabilitation, Mail Point 886 Southampton General Hospital, Tremona Road, Southampton SO16 6YD
Email: [redacted], Tel: [redacted]

Date: 20/11/2013, V.3

Appendix 16: Children information sheet (chapters 5 & 6)

Thank you very much for reading this information. If you want to take part in the study, talk to your parents and they will let us know.

4 Date:03/06/2013, V.2, Ethics #: 5520

Participant Information Sheet for children

Would you like to take part in our study?

It is about:

Can the Wii-Fit games make you stand with a better balance?

Date:03/06/2013, V.2, Ethics #: 5520 1

We are doing research about the Wii-Fit video games. We want to see if playing with Wii-Fit games can make you more balanced when you stand.

Do I have to take part in this study?

No, it's up to you. If you want to take part in the study but change your mind later, that's fine too. It is OK to leave the study whenever you want without telling us why.

What will happen if I take part?

If you join the study we will contact your parents to bring you to meet us at Rose Road. We will explain what you have to do and you can ask us any questions, and then you will fill in a form.

We will check your weight and height. Then a physiotherapist will ask you to do few things, like walking few steps or standing for one min, and then check how strong your leg muscles are.

After that, you will play four games of the Wii-fit to be sure that you are safe to play the games.

Then you will visit us again to test your balance. We will ask you to stand on the Wii-balance board to see how good your standing balance is, and we will ask you to do other things like walking or standing to see how good your balance is when you move around. We will video record it with video camera.

2 Date:03/06/2013, V.2, Ethics #: 5520

Then we will contact your parents to bring you to Rose Road **3 times every week** after school to play with the Wii-fit games for **30 min**. each time you will **play 4 games** 3 times and you will rest between them. This will be for **4 weeks**, in all we shall see you **15** times.

After 4 weeks of playing with the Wii-fit games, we will test your balance again to check for any changes. We will record this with a video camera.

Will anyone know I'm doing this?

Only the researchers will know. We will only use information after removing your name and replacing it with a code number, so no one else will know that you are doing this study.

What if there is something about the study that upset me?

If you feel upset during the study, or if you feel any pain, tired, bored or don't want to do it you can stop at any time. If you have any questions or are unhappy about anything, tell your parents. They will know who to call.

Date:03/06/2013, V.2, Ethics #: 5520 3

Appendix 17: GMFCS Family Report Questionnaire

GMFCS Family Report Questionnaire: Children Aged 6 to 12 Years

Please read the following and mark **only one box** beside the description that best represents your child's movement abilities.

My child...

- ☐ **Has difficulty sitting on their own and controlling their head and body posture in most positions**
  and has difficulty achieving any voluntary control of movement
  and needs a specially supportive chair to sit comfortably
  and has to be lifted or hoisted by another person to move

- ☐ **Can sit on their own but does not stand or walk without significant support**
  and therefore relies mostly on wheelchair at home, school and in the community
  and often needs extra body / trunk support to improve arm and hand function
  and may achieve self-mobility using a powered wheelchair

- ☐ **Can stand on their own and only walks using a walking aid** (such as a walker, rollator, crutches, canes, etc.)
  and finds it difficult to climb stairs, or walk on uneven surfaces
  and may use a wheelchair when travelling for long distances or in crowds

- ☐ **Can walk on their own without using walking aids, but needs to hold the handrail when going up or down stairs**
  and often finds it difficult to walk on uneven surfaces, slopes or in crowds

- ☐ **Can walk on their own without using walking aids, and can go up or down stairs without needing to hold the handrail**
  and walks wherever they want to go (including uneven surfaces, slopes or in crowds)
  and can run and jump although their speed, balance, and coordination may be slightly limited

© Chris Morris, 2007
Available from *CanChild* Centre for Childhood Disability Research (www.canchild.ca), McMaster University
GMFCS modified with permission from Palisano et al. (1997) Dev Med Child Neurol, 39, 214-223.

Appendix 18: Reply slip (chapter 5& 6)

Reply slip

Title of project: The effect of Wii-Fit balance games on children with cerebral palsy

Name of researcher: Afrah Almuwais **Ethics number**: 5520

I am returning this form to indicate that I am willing to consider taking part in the above study

Name of parent	
Name of child	
Age of the child	
How many sessions per week would you like your child to attend?	2 sessions per week OR 3 sessions per week
What days of the week are the most convenient to you and your child for the sessions?	Monday – Tuesday – Wednesday – Thursday – Friday
What time would you like your child's sessions to start?	3:30 pm 4 pm 4:30 pm 5 pm Or Other earlier times, please specify………………
Would like us to arrange a Taxi for you?	Yes No

Signature ……………………………………

Date……………………………………….

When completed please return in the FREE POST envelop provided, or to {Afrah Almuwais, building 45, faculty of health sciences, university of Southampton, Southampton, SO17 1BJ}.

Appendix 19: Advert posted in electronic newsletters and public newspaper (chapter 5 & 6)

Research on the use of Wii-Fit games for children with cerebral palsy

- Do you have a child between the age of 6 and 12 years who has been diagnosed with cerebral palsy?
- We are looking for volunteers to take part in the study, which will explore the effect of Wii-Fit balance games in improving standing balance in children with cerebral palsy.
- The study will be held at Rose Road. Travel expenses will be covered and refreshments will be served.

If you are interested in the study and would like your child to take part, please contact **Afrah**

(Email: , Tel:) for further information

Appendix 20: NHS ethics approval (chapter 5 & 6)

1

NHS
Health Research Authority
National Research Ethics Service

NRES Committee North West - Preston
HRA NRES Centre - Manchester
Barlow House
3rd Floor
4 Minshull Street
Manchester
M1 3DZ

Telephone: 0161 625 7818
Facsimile: 0161 625 7299

19 February 2014

Mrs Afrah Almuwais
Building 45, Faculty of Health Sciences
University of Southampton
Southampton
SO17 1BJ

Dear Mrs Almuwais

Study title:	**The effect of Wii-Fit balance games on standing postural control in children with cerebral palsy**
REC reference:	**14/NW/0105**
Protocol number:	**faculty ethics (5520)**
IRAS project ID:	**148605**

The Proportionate Review Sub-committee of the NRES Committee North West - Preston reviewed the above application on 18 February 2014.

We plan to publish your research summary wording for the above study on the NRES website, together with your contact details, unless you expressly withhold permission to do so. Publication will be no earlier than three months from the date of this favourable opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to withhold permission to publish, please contact the REC Manager Mrs Carol Ebenezer, nrescommittee.northwest-preston@nhs.net.

Ethical opinion

On behalf of the Committee, the sub-committee gave a favourable ethical opinion of the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

Ethical review of research sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

2

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

<u>Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.</u>

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of approvals from host organisations.

<u>Registration of Clinical Trials</u>

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database within 6 weeks of recruitment of the first participant (for medical device studies, within the timeline determined by the current registration and publication trees).

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non clinical trials this is not currently mandatory.

If a sponsor wishes to contest the need for registration they should contact Catherine Blewett (catherineblewett@nhs.net), the HRA does not, however, expect exceptions to be made. Guidance on where to register is provided within IRAS.

Further Condition specified by the Committee

a. the committee would like to see the Consent Form revised to include a further clause "I understand that data from the study may be looked at by regulatory authorities or by persons from the Trust where it is relevant to my taking part in this study. I agree to these persons having access to this data"

You should notify the REC in writing once all conditions have been met (except for site approvals from host organisations) and provide copies of any revised documentation with updated version numbers. The REC will acknowledge receipt and provide a final list of the approved documentation for the study, which can be made available to host organisations to facilitate their permission for the study. Failure to provide the final versions to the REC may cause delay in obtaining permissions.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

3

Approved documents

The documents reviewed and approved were:

Document	Version	Date
Evidence of insurance or indemnity		30 January 2014
Investigator CV	Almuwais	
Investigator CV	Ashburn	28 January 2014
Investigator CV	Stack	28 January 2014
Letter from Sponsor	Email	30 January 2014
Letter from Statistician	Email	26 April 2013
Letter of invitation to participant	2	03 June 2013
Other: Reply Slip		
Participant Consent Form: Parents	3	20 November 2013
Participant Consent Form: Assent	2	03 June 2013
Participant Information Sheet: Parents	3	20 November 2013
Participant Information Sheet: Children	2	03 June 2013
Protocol	2	30 January 2014
Questionnaire: GMFCS Family Report Questionnaire		
REC application	3.5	06 February 2014
Referees or other scientific critique report		13 April 2013

Membership of the Proportionate Review Sub-Committee

The members of the Sub-Committee who took part in the review are listed on the attached sheet.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document "After ethical review – guidance for researchers" gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The NRES website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the website.

4
information is available at National Research Ethics Service website > After Review

14/NW/0105	**Please quote this number on all correspondence**

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

With the Committee's best wishes for the success of this project.

Yours sincerely

Dr Patricia Wilkinson
Chair

Email: nrescommittee.northwest-preston@nhs.net

Enclosures:	*List of names and professions of members who took part in the review*
	"After ethical review – guidance for researchers"
Copy to:	*Barbara Halliday, university of southampton* *Catherine Lea, Solent NHS trust*

Appendix 21: Solent NHS trust R&D approval (chapter 5& 6)

Solent NHS
NHS Trust

2nd Floor Adelaide Health Centre
Western Community Hospital Campus
William Macleod Way
Southampton
Hampshire, SO16 4XE
T: 023 8060 8925
E: Research@solent.nhs.uk

Ref: SW / cl

24th March 2014

Miss A Almuwais
University of Southampton
Faculty of Health Sciences
Building 45
University of Southampton
Southampton
SO17 1BJ

Dear Miss Almuwais

R&D No.: **SR/006/14**
CSP No.: **N/a**
Study Title: **The Effect of Wii-Fit Balance Games on Standing Postural Control in Children with Cerebral Palsy**

In accordance with the Department of Health's Research Governance Framework for Health and Social Care, all research projects taking place within the Trust must receive a favourable opinion from an ethics committee and permission from the Department of Research and Development (R&D) prior to commencement.

Solent NHS Trust has reviewed the documentation submitted for the above research study and I am pleased to confirm NHS permission. The PICs where you are permitted to undertake the research are listed in the attached appendix. The addition of a new site(s) **must be notified** to Solent Research by submitting an SSI form and for PICs, a revised R&D Form.

I would like to bring your attention to the attached list of conditions of approval and specifically to:

a) The mandatory requirement to record the recruitment for all sites within this Trust onto the e-dge™ database (**information about this is attached**).

b) The mandatory requirement to report annually to the Trust on the study progress, and submit all publications resulting from the study to Solent NHS Trust for them to share with patients and staff.

c) The understanding that your study will be subject to monitoring and / or audit by the research team.

Documents Reviewed

Document	Version	Date
Protocol	2.0	30/01/14
Participant Information Sheets – Parents	3.0	20/11/13
Participant Information Sheets - Children	2.0	20/11/13
Consent Forms – Parents	3.0	20/11/13
Consent Forms – Children Assent	2.0	03/06/13
Invitation to Participate	2.0	03/06/13
Reply Slip		
Questionnaire: GMFCS Family Report Questionnaire		
Indemnity / Insurance		30/01/14
Sponsors Letter		30/01/14
Funders Letter		
CV – Chief Investigator – Afrah Almuwais		28/01/14

I wish you every success with your study. If you require support or assistance at any time with the involvement of Solent NHS Trust in this study, please don't hesitate to contact us.

Yours sincerely

Dr Sarah Williams
Head of Research & Clinical Audit

INVESTOR IN PEOPLE

Solent NHS Trust Headquarters
Adelaide Health Centre, William Macleod Way, Millbrook, Southampton SO16 4XE
Telephone: 023 8060 8900 Fax: 023 8053 8740 Website: www.solent.nhs.uk

Appendix 22: KFMC ethical approval (chapter 5 & 6)

Kingdom of Saudi Arabia
Ministry of Health
King Fahad Medical City
(162)

وزارة الصحة
مدينه الملك فهد الطبية
King Fahad Medical City

المملكة العربية السعودية
وزارة الصحة
مدينه الملك فهد الطبية
(١٦٢)

IRB Registration Number with KACST, KSA: H-01-R-012
IRB Registration Number with OHRP/NIH, USA: IRB00008644
Approval Number Federal Wide Assurance NIH, USA: FWA00018774

May 19, 2014
IRB Log Number: 14-119E
Department: External
Category of Approval: EXPEDITED

Dear Afrah Almuwais:

I am pleased to inform you that submission dated May 15, 2014 for the study titled **'The effect of Wii-Fit balance games on standing postural control in children with cerebral palsy'** was reviewed and was approved according to Good Clinical Practice guidelines.

Please be informed that in conducting this study, you as the Principal Investigator are required to abide by the rules and regulations of the Government of Saudi Arabia, the KFMC/IRB policies and procedures, and the IHC Good Clinical Practice guidelines. Further, you are required to submit a Progress Report before April 19, 2015; it can be reviewed by the IRB without lapse of approval. The approval of this proposal will automatically be suspended on May 19, 2015 pending the acceptance of the Progress Report. You also need to notify the IRB as soon as possible in the case of:

1. Any amendments to the project;
2. Termination of the study;
3. Any serious unexpected adverse events (within two working days);
4. Any event or new information that may affect the benefit/risk ratio of the proposal.

Please observe the following:

1. Personal identifying data should only be collected when necessary for research;
2. The data collected should only be used for this proposal;
3. Data should be stored securely so that a few authorized users are permitted access to the database;
4. Secondary disclosure of personal identifiable data is not allowed;
5. Copy of the Consent Form should be kept in the Research Subject's Medical Record and the consent process should be documented in the medical record.

We wish you every success in your research endeavor.

مدينة الملك فهد الطبية
King Fahad Medical City

Kingdom of Saudi Arabia
Ministry of Health
King Fahad Medical City
(162)

مدينه الملك فهد الطبية
King Fahad Medical City

المملكة العربية السعودية
وزارة الصحة
مدينه الملك فهد الطبية
(١٦٢)

If you have any further questions feel free to contact me.

Sincerely yours,

Prof. Omar H. Kasule
Chairman Institutional Review Board--IRB.
King Fahd Medical City, Riyadh, KSA
Tel: + 966 1 288 9999 Ext. 7540
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KFMC
Approved
19 MAY 2014
IRB

وزارة الصحة
مدينه الملك فهد الطبية
King Fahad Medical City

Appendix 23: Invitation letter to parents in Arabic (chapter 5 & 6)

UNIVERSITY OF Southampton

التاريخ:01/06/2014

دعوة لطفلك للمشاركة في دراسة حول ألعاب التوازن (Wii-Fit)

عزيزتي الأم الفاضلة,

السلام عليكم ورحمه الله وبركاته

هذي الرساله هي دعوة طفلك للمشاركة في دراسة بحثية تبحث في إذا ألعاب التوازن (Wii-Fit) يمكن ان تستخدم كوسيله علاج لتحسين التوازن لدى الأطفال المصابين بالشلل الدماغي .

سيطلب من طفلك اللعب بألعاب التوازن (Wii-Fit) لمدة 30 دقيقة، 3 مرات في الأسبوع، لمدة 4 أسابيع. وستعقد الجلسات في مدينة الملك فهد الطبية في الأوقات المناسبة لك ولطفلك. مزيد من المعلومات حول هذا البحث في المرفق "ورقة المعلومات الأم" لكي و "ورقة معلومات الطفل" لطفلك .

وبمجرد الإنتهاء من قراءة ورقة المعلومات، وانتي موافقة لطفلك للمشاركة في هذه الدراسة لا تترددي في الاتصال بي؛ معلومات الإتصال الخاصة بي في اسفل هذه الرسالة وورقة المعلومات المرفقة .

لكي مني جزيل الشكر على قراءة هذي الدعوه و الأوراق المرفقة.

تفضلي بقبول فائق احترامي،

أفراح المويس

طالبه دكتوراه في جامعه ساوثهامتن,بريطانيا

هاتف:

البريد الإلكتروني :

Date: 6/5/2014, V.3, Ethics# 5520

Appendix 24: Parents' information sheet in Arabic (chapter 5 & 6)

UNIVERSITY OF Southampton

ورقة معلومات الام

عنوان الدراسة: تأثير العاب التوازن (Wii-Fit) على الأطفال المصابين بالشلل الدماغي

الباحثه: أفراح المويس
البحث رقم: 5520

إذا طفلك تم تشخيصه بالشلل الدماغي،اذن طفلك من المدعوين للمشاركة في هذه الدراسة البحثية. قبل أن تقرري إذا كنتي ترغبين له أو لها للمشاركة، فمن الضروري أن شرح الغرض من البحث وما سوف يحتوي عليه. يرجى أخذ الوقت لقراءة المعلومات التالية. إذا كنت موافقه لطفلك للمشاركة، يرجى الاتصال بنا. بالإضافة إلى ذلك، سوف يطلب منك التوقيع على استمارة الموافقة. يرجى الاتصال بنا اذا كنت تريدين مزيد من المعلومات أو إذا كان أي شيء غير واضح.

ما هو البحث عنه؟

لعبة (Wii-Fit) هي لعبة ممتعة للأطفال والكبار. وقد أظهرت الأبحاث السابقة أن العاب (Wii-Fit) يمكن أن تفيد الاشخاص في التحكم في التوازن . وهناك حاجة للتوازن للأطفال المصابين بالشلل الدماغي في الأنشطة اليومية. في هذه الدراسة نريد أن نرى ما اذا كان اللعب بألعاب (وى صالح) يمكن ان يحسن التوازن عند الأطفال المصابين بالشلل الدماغي أو لا .

لماذا تمت دعوة طفلي ؟

لقد دعي طفلك للمشاركة في هذه الدراسة لأن لديه تشخيص بالشلل الدماغي، ويتراوح عمره بين 6 إلى 12 سنة، ولديه القدره الوظيفية المناسبة على اللعب بألعاب (Wii-Fit) وانها لن تكون صعبة أو خطره له اثناء اللعب.

هل يتوجب على طفلي المشاركة؟

لكي حريه القرار بشأن ما إذا كنت تريدين لطفلك المشاركة في هذه الدراسة أو لا . إذا قررتي السماح لطفلك بالمشاركة، سيطلب منك التوقيع على استمارة الموافقة. وسوف تعطى طفلك ورقة المعلومات أيضا، وسيتم إعطاءه خيار ليقرر بأن يشارك في هذه الدراسة أم لا. بالإضافة إلى ذلك، سيكون لطفلك حريه الانسحاب من الدراسة في أي وقت دون الحاجة لاعطاء سبب.

ما سوف يحدث لطفلي إذا وافقت له\لها بالمشاركه ؟

إذا كنت تريد لطفلك للمشاركة في هذه الدراسة ، يرجى الاتصال بنا. بمجرد الاتصال بنا، يمكنك أن تسأل أي أسئلة أخرى حول البحث و سوف نقوم بترتيب وقتا مناسب لك ولطفلك لتحديد الجلسات.
سوف التقي بكم في عيادة العلاج الطبيعي للأطفال في مدينة الملك فهد الطبية و نتجه إلى غرفة حيث سيتم مناقشة الإجراءات. إذا كنت موافقه لطفلك للمشاركة ، سوف يطلب منك التوقيع على استمارة الموافقة . وسوف يطلب من طفلك ملء استمارة الموافقة الخاصه بالاطفال أيضا. ثم سيطلب منك أن تجيب على بعض الأسئلة القليلة حول طفلك ، بالإضافة إلى ذلك، سوف يتم تقييم وزن طفلك ، وطوله، مستواه الوظيفي، و قوة عضلاته من قبل أخصائيه العلاج الطبيعي التي ستحضر كل الجلسات التدريبية و القياسيه لطفلك. بعد ذلك سوف يسمح للطفل باللعب باربع العاب لمرة واحدة وذلك للتعرف على الألعاب والتاقلم معها قبل بدء الجلسات التدريبية والتأكد فإن الطفل سوف يكون آمن عند اللعب. الزيارة الأولى سوف تستغرق حوالي 30-40 دقيقة.
بعد ذلك سيكون هناك جلستان لقياس التوازن، قبل الجلسات التدريبية وبعد. وسوف تشمل هاتان الجلستان قياس توازن طفلك اثناء الوقوف على لوح التوازن (Wii-balance-board) لمدة 30 ثانية ، 3 مرات مع عيون مفتوحة ، و 3 مرات مع عيون مغلقة . ثم سيطلب من الطفل أداء بعض النشاطات لقياس مستوى التوازن الوظيفي .
هاتان الجلستان ستكون مسجله بالفيديو لاجراء المزيد من التحقيقات . يرجى ملاحظة أن جلستان القياس فقط سيتم

تسجيلها ، ولن يرى احد أشرطة الفيديو المسجلة غير الباحثه و فريق البحث وسوف يتم تدميرها على الفور في نهاية الدراسة. تشتمل الجلسات التدريبية على العلاج عن طريق اللعب بأربع العاب مخصصه للتوازن (Wii-Fit) لمدة 30 دقيقة، 3 مرات في الأسبوع، لمدة 4 أسابيع. كل الجلسات ستتم في مدينة الملك فهد الطبية . وستحضر أخصائيه العلاج الطبيعي جميع الجلسات لسلامة طفلك . سوف يطلب منك التفضل لحضور الجلسات مع طفلك. **نفقات النقل من وإلى مدينة الملك فهد الطبية ستدفع لك.**

هل هناك أي فوائد لطفلي اذا شارك في البحث ؟

يمكن أن يستفيد طفلك من التدريب للتوازن وقد يجد طفلك متعة مع الألعاب . ومن المؤمل أن المعلومات المكتسبة من هذه الدراسة سوف تساعدنا في المستقبل لاستخدام الألعاب (Wii-Fit) في عيادات التأهيل للأطفال المصابين بالشلل الدماغي. في نهاية الدراسة ، وسيتم إعطاء كل طفل شارك شهادة تقدير . بالإضافة إلى ذلك، **سوف توضع جميع أسماء الأطفال المشاركين في وعاء للسحب على الفوز بلعبه وي نينتندو(Wii-Fit) مع لوح التوازن (Wii-balance-board).**

ما هي الآثار الجانبية لالعلاج عندما يشارك طفلي في هذه الدراسة ؟

ليس هناك أي آثار جانبية معروفة عند المشاركة في هذه الدراسة. بالإضافة إلى ذلك، المشاركه في هذه الدراسة لن تؤثر على العلاج الطبيعي المعتاد لطفلك.

هل مشاركة طفلي في هذه الدراسة ستكون سرية ؟

نعم ، وجميع المعلومات التي تم جمعها خلال عملية البحث تبقى سرية. فإن أي البيانات التي يتم جمعها منك أومن طفلك لن يكن عليها اسم طفلك، حيث سيتم تخصيص رمز خاص لكل طفل بحيث لن يتم التعرف عليه. سيتم تخزين المعلومات على جهاز كمبيوتر محمول محمي بكلمة مرور التي سيتم تخزينها في خزانة مقفلة في الجامعة. سيتم الاحتفاظ بالمعلومات داخل الجامعة لمدة 10 عاما.

ماذا سيحدث لنتائج الدراسة البحثية ؟

سيتم تحويل المعلومات المسجلة من أدوات التقييم الى أرقام لتحليلها. ويمكن أيضا أن تكون النتائج مكتوبة في المقالات والبحوث المنشورة في المؤتمرات أو في المجلات الأكاديمية . إذا حدث هذا، لن يتم التعرف على طفلك.

من قام بالاطلاع على اجراءات الدراسة وافق عليها؟

تم الاطلاع والموافقه على هذه الدراسه من قبل لجنة الأخلاقيات البحثيه في كلية العلوم الصحية، جامعة ساوثهامبتون (البحث رقم: 5520) ، و مكتب مركز الأبحاث في مدينة الملك فهد الطبية (البحث رقم:14-119E)

ماذا تفعل إذا كنت ترغب في تقديم شكوى.

إذا كان لديك قلق أو شكوى حول هذه الدراسة يمكنك الاتصال بالسيدة باربرا (Barbara Halliday) ، رئيسة إدارة البحوث (العنوان: University of Southampton, Building 37, Highfield, Southampton, SO17 1BJ ؛ هاتف +، فاكس + ؛ البريد الإلكتروني)أنها ستوفر لك تفاصيل إجراءات الشكاوى من جامعة ساوثهامبتون.

شكرا لأخذ الوقت الكافي لقراءة ورقة المعلومات هذه

إذا كنت ترغب في أي مزيد من المعلومات يرجى الاتصال ب :

الباحثه: أفراح المويس (هاتف: , البريد الإلكتروني :)

المشرفه :البروفيسور آن اشبورن (Prof. Ann Ashburn, Tel: +, Email:)

Date: 06/05/2014, V.4, Ethics #: 5520

Appendix 25: Children information sheet in Arabic (chapter 5 & 6)

ورقة معلومات للأطفال

هل ترغب في المشاركة في دراستنا؟

هي عبارة عن:

هل يمكن لألعاب (Wii-Fit) أن تجعلك تقف بتوازن أفضل؟

Date:08/05/2014, V.2(1), Ethics #: 5520 1

شكرا جزيلا لقراءة هذه المعلومات. إذا كنت ترغب في المشاركة في هذه الدراسة، تحدث مع والدتك ، وهي ستتصل بنا

4 Date:08/05/2013, V.2(1), Ethics #: 5520

نحن نجري دراسه لنبحث عن إجابه لسؤالنا : هل ألعاب الفيديو (Wii-Fit) يمكن أن تجعلك أكثر توازناً عندما تقف؟

هل يجب أن أشارك في هذه الدراسة؟

لا، لك حرية الاختيار. وإذا كنت ترغب في المشاركة في الدراسة ولكن غيرت رأيك لاحقا، فلا بأس أن تترك الدراسة وقتما تشاء دون أن تخبرنا لماذا

ماذا سيحدث عندما أشارك؟

سوف تتصل والدتك بنا و تحضرك لمقابلتنا وسوف نشرح لك ما عليك القيام به ويمكنك أن تسألنا أي أسئلة، وبعد ذلك سوف نملء بعض الاوراق .

وسوف نقوم بقياس وزنك، وطولك. ثم اخصائيه العلاج الطبيعي سوف تطلب منك أن تفعل بعض الأشياء، مثل المشي خطوات قليلة أو الوقوف لدقيقة واحدة، ومن ثم تتحقق مدى قوة عضلات ساقيك .

بعد ذلك، سوف تلعب أربع ألعاب من (Wii-Fit) لنتطمن أنها آمنة لك.

بعدها سوف تقوم بزيارتنا مرة أخرى لقياس توازنك. سوف نطلب منك أن تقف على لوح التوازن (Wii-balance-board) لنرى ان كان توازنك عند الوقوف جيد. وسوف نطلب منك أن تفعل أشياء أخرى مثل المشي أو الوقوف لنرى توازنك عند التحرك. وسنقوم بتسجيل هذا بكاميرا الفيديو .

تم ستقوم بزيارتنا 3 مرات كل أسبوع للعب مع الألعاب هذه لمدة 30 دقيقة. في كل مرة سوف تلعب 4 ألعاب كل لعبه 3 مرات، وسوف يستريح بينهما. وسوف يكون هذا لمدة 4 أسابيع .بعد 4 أسابيع من اللعب مع ألعاب (Wii-Fit)، سنقوم بقياس توازنك مرة أخرى للتحقق من أية تغييرات. وسنقوم بتسجيل هذه القياسات بكاميرا الفيديو.

هل يعرف أحد أنني مشارك ؟

فقط الباحثه وفريق البحث. سوف نستخدم فقط المعلومات بعد إزالة اسمك واستبدالها برمز، لذلك لا أحد آخر سوف يعرف أنك تشارك بهذه الدراسة .

ماذا لو كان هناك شيئا يزعجني عن الدراسة؟

إذا تضايقت أثناء مشاركتك في الدراسة، أو إذا كنت تشعر بأي ألم، أوتعب او ملل و لا تريد ان تفعل ذلك يمكنك التوقف في أي وقت. إذا كان لديك أي أسئلة أو غير راضي عن أي شيء، أخبر والدتك وهي تعلم بمن تتصل .

Appendix 26: Parents' consent form (chapter 5 & 6)

UNIVERSITY OF Southampton

Study title: The effect of Wii-Fit balance games on standing postural control in children with cerebral palsy

Researcher name: Afrah Almuwais
Ethics reference: 5520

Please initial the box(es) if you agree with the statement(s):

I have read and understood the information sheet (date: 20/11/2013, version no.3) of parents' information sheet and have had the opportunity to ask questions about the study. ☐

I agree for my child to take part in this research project and agree for my child to be video recorded during measurement sessions, and agree for my child's data to be used for the ☐

I understand my child's participation is voluntary and my child may withdraw at any time ☐

I agree that non-identifiable photos of my child may be used in describing the research and present findings in conferences and journal publications ☐

I am happy to be contacted regarding other unspecified research projects. I therefore consent to the University retaining my personal details on a database, kept separately from the research data detailed above. The 'validity' of my consent is conditional upon the University complying with the Data Protection Act and I understand that I can request my details be removed from this database at any time. ☐

I agree to allow my child ______________________________ {child's name} to participate in the above study.

Data Protection
I understand that information collected about me during my participation in this study will be stored on a password protected computer and that this information will only be used for the purpose of this study. All files containing any personal data will be made anonymous.

Name of parent (print name)…………………………………………………

Signature of parent …………………………………………………………..

Date…………………………………………………………………………

Date: 20/11/2013, *V.3*

Appendix 27: Child assent form (chapter 5 &6)

Assent Form for Children

(Completed by the child with their parent or with researcher after parent's consent)

Title of Project: The effect of Wii-Fit balance games on standing postural control in children with cerebral palsy

Name of researcher: Afrah Almuwais **Ethics Number:** 5520

Please circle all they agree with:

Has somebody explained this study to you?	Yes / No
Have you asked all the questions you want?	Yes / No
Do you understand it's OK to say No and stop at any time?	Yes / No
Are you happy to take part?	Yes / No
Are you happy to be video recorded with camera?	Yes / No

If any answers are **'No'** or you **don't** want to take part, **don't** sign your name

If you **do want** to take part, you can **write** your name below

Your name ___________________________

Date __________________________

The Person who explained this project to you needs to sign too:

________________________ _______________ ______________________

Name Date Signature

Thank you for your help.

(Date: 03/06/2013, V.2)

Appendix 28: Parents' consent form in Arabic (chapter 5 &6)

UNIVERSITY OF Southampton

موافقة الأم

Date: 08/05/2014, V. 4

عنوان الدراسة: تأثير العاب التوازن (Wii-Fit) على الأطفال المصابين بالشلل الدماغي

الباحثه: أفراح المويس
البحث رقم: 5520

الرجاء وضع الحرف الاول من اسمك في المربع (المربعات) المقابل للجمله (الجمل) التي تتفقين معها :

لقد قرأت وفهمت ورقة المعلومات للأم (تاريخ: 5/6/2014، نسخة NO.4) واتيحت لي فرصة لطرح الأسئلة حول الدراسة. ☐

وأنا أوافق لطفلي المشاركة في هذه الدراسة البحثية وأوافق أن يتم تسجيل جلسات قياس التوازن بالفيديو واستخدام البيانات لغرض هذه الدراسة ☐

أنا أفهم ان مشاركة طفلي تطوعية وبإمكانه الإنسحاب في أي وقت دون إبداء أي أسباب ☐

أوافق على أن تؤخذ صور طفلي (دون ظهور الوجه) لاستخدام هذه الصور في وصف نتائج البحث في المؤتمرات و المقالات المنشورة ☐

أنا أوافق على السماح لطفلي ______________________ {اسم الطفل} بالمشاركة في الدراسة أعلاه .

حماية البيانات
أنا أفهم أن المعلومات التي تم جمعها حول طفلي خلال مشاركته في هذه الدراسة سوف يتم تخزينها على جهاز كمبيوتر محمي بكلمة مرور والتي لن تستخدم إلا لغرض هذه الدراسة. وسوف تكون سريه ولا تحتوي على أي بيانات شخصية .

اسم الأم ....

توقيع الأم ....

تاريخ ....

Appendix 29: Child Assent form in Arabic (chapter 5 &6)

UNIVERSITY OF Southampton

نموذج موافقه الطفل

Date: 03/06/2013, V.2

(تم تعبئته من قبل الطفل مع مساعده الأم أو الباحثه بعد موافقة الأم)

عنوان الدراسة: تأثير العاب التوازن (Wii-Fit) على الأطفال المصابين بالشلل الدماغي

الباحثه: أفراح المويس

البحث رقم: 5520

ضع دائرة حول كل ما تتفق معه :

1. **هل شرح أحدهم هذه الدراسة لك؟** نعم / لا
2. **هل سألت كل الأسئلة التي تريد ان تسألها؟** نعم / لا
3. **هل تعلم انك تستطيع ان تقول لا، وتتوقف في أي وقت؟** نعم / لا
4. **هل تريد المشاركة ؟** نعم / لا
5. **هل أنت موافق ان يتم تسجيل جلسات القياس بالكاميرا الفيديو؟** نعم / لا

اذا كانت الإجابة هي "لا" أو أنك لا تريد أن تشارك,لا توقع باسمك

إذا كنت تريد أن شارك يمكنك كتابة اسمك أدناه

اسمك …………………………………………………

تاريخ.....………………………………………………

الشخص الذي شرح هذه الدراسه لك يحتاج إلى توقيع هنا :

………………………	…………………………..	………………………………
الاسم	**التوقيع**	**التاريخ**

Appendix 30: Child assessment form (chapter 5 & 6)

Child Assessment Form (Date: 08/05/2014, V.3)

UNIVERSITY OF Southampton

Date: ☐☐☐☐☐☐ (dd/mm/yy)

ID Number ☐☐☐

Part A: To be filled by the parent

1. Please tick as appropriate:

1.1 Your queries about the study have been answered to your satisfaction ………………. ☐

1.2 You have signed the consent form…………………………………………………… ☐

1.3 Your child has a diagnosis of cerebral palsy…………………………………………. ☐

1.4 You have filled the GMFCS family report questionnaire ……………………………. ☐

1.5 Which part of your child's body has been affected;

a. Four limbs (both arms and both legs) …………………………………………… ☐

b. Two lower limbs (both legs) ………………………………………………….… ☐

c. Two limbs on right side (one arm and one leg) ……………………………….. ☐

d. Two limbs on left side (one arm and one leg) ……………………………….…. ☐

e. One limb only, which limb_________ on which side_________ ☐

2. Please answer the following questions by circling Yes or No

2.1 Has your child had any spinal surgery or lower limbs surgery during the last 3 months?	Yes	No
If yes, please give details.		
2.2 Has your child had botulinum toxin (botox) injections during the last 6 months?	Yes	No
If yes, please give details		

2.2 Has your child experienced any uncontrolled seizures?	Yes	No
If yes, please give details.		
2.3 Has your child had an ear infection during the last 6 weeks?	Yes	No
If yes, please give details.		
2.4 Does your child have any hearing impairment?	Yes	No
If yes, please give details.		
2.5 Does your child have normal or corrected to normal vision?	Yes	No
If yes, please give details.		
2.6 Is your child currently participating in any other research studies?	Yes	No
If yes, please give details.		

3. Please fill in the following details about your child:

3.1 Gender __________ (M/F)

3.2 Date of birth ________________ (dd/mm/yy)

3.3 Age ___________ years

3.4 How many sessions of physiotherapy does your child receive every week ________ and how long does each session take ________

3.5 What therapy does your child receive other than physical therapy __________________________ , how may sessions every week __________ and for how long does each session last ______________

3.6 If your child uses walking aids, what type of walking aids does your child use

____

3.7 If your child uses any ankle-foot orthotics or any shoes insole, please give details

____

Part B: To be filled by physiotherapist

4. Physical assessment to be carried out by physiotherapist

4.1 Height __________ cm

4.2 Weight _________ kg

4.3 BMI _________

4.4 GMFCS level _________

4.5 The child is characterised as:

Diplegic ☐

Hemiplegic ☐

Quadriplegic ☐

4.6 The child's overall muscle tone is characterised as:

Spastic ☐

Hypotonic ☐

Athetoid ☐

Ataxic ☐

4.7 The child's muscle tone score in the following muscles using the Modified Ashworth Scale

Joint	Muscles	Right side	Left side
Ankle	Dorsi-flexors		
	Planter-flexors		
Knee	Flexors		
	Extensors		
Hip	Flexors		
	Extensors		
	Adductors		
	Abductors		

Note: Modified Ashworth Scale (Peacock & Staudt, 1991) score description is:

Score 0: (Hypotonic) Less than normal muscle tone, floppy

Score 1:	(Normal)	No increase in muscle tone
Score 2:	(Mild)	Slight increase in muscle tone, 'catch' in limb movement or minimal resistance to movement through less than half of the range
Score 3:	(Moderate)	Marked increase in muscle tone through most of the range of motion but the passive movement of the affected part is easily performed
Score 4:	(Severe)	Considerable increase in muscle tone, passive movement difficult
Score 5:	(Extreme)	Affected part rigid in flexion or extension

4.8 Describe the child's standing body posture

Head

Neck

Trunk

Hip

Knee

Ankle

Please answer by circling yes or no, if the child was able to perform the following tasks :

5. Standing functional ability		
5.1 Stands and maintains arms free for 1 min.	Yes	No
5.2 Stands holding on to bench with one hand, lifts right foot, for 3 seconds	Yes	No
5.3 Stands holding on to bench with one hand, lifts left foot for 3 seconds	Yes	No
5.3 Stands and lifts left foot, arms free for 10 seconds	Yes	No
5.4 Stands and lifts right foot, arms free for 10 seconds	Yes	No
5.5 Stands from sitting without support	Yes	No
5.6 Stands and walks forward 10 steps	Yes	No
5.7 Stands and walks forward 10 steps, stops, turns 180 degree and walks back	Yes	No
5.8 Stands and kicks ball with right foot	Yes	No

5.9 Stands and kicks a ball with left foot	Yes	No
6. Ability to play the games		
6.1 The child's posture does not affect him/her playing the games	Yes	No
6.2 The child is able to step on the WBB without support (but with supervision)	Yes	No
6.3 The child is able to stand and play a game for 3 min	Yes	No
6.4 The child is able to sit on the chair without support (but supervision) to rest	Yes	No
6.5 The child is able to understand and follow verbal commands	Yes	No
6.6 The child is able to understand the instructions for the games	Yes	No
6.7 The child is able to play 'Soccer heading' game without risk of falling	Yes	No
6.8 The child is able to play 'Penguin slide' game without risk of falling	Yes	No
6.9 The child is able to play 'Ski Slalom' game without risk of falling	Yes	No
6.10 The child is able to play 'Table tilt' game without risk of falling	Yes	No
6.11 The child showed signs of fatigue (even when rests were given)	Yes	No

6.12 The child has enjoyed playing:

Soccer heading ☐

Penguin slide ☐

Ski Slalom ☐

Table tilt ☐

If the child has given any reason why they disliked a game, please state here

____

Physiotherapist's name ……………………………….

Date…………………………….

Signature ……………………….

Appendix 31: Child assessment form (part A only) in Arabic (chapter 5 & 6)

UNIVERSITY OF Southampton

نموذج تقييم الطفل

Date: 08/05/2014, V.3

ID Number ☐☐☐

التاريخ :..

الجزء (أ) : تتم تعبئته من قبل الأم

1. يرجى وضع علامة (ا) في المربع المقابل للجملة التي تتفقين معها **:**

1.1 هل تمت الإجابه عن أسئلتك و استفساراتك حول الدراسة .... ☐

1.2 هل وقعتي على استمارة الموافقة.. ☐

2. الرجاء الإجابة على الأسئلة التالية بوضع دائرة حول نعم أو لا**:**

2.1 هل اجريت أي عملية جراحية في العمود الفقري أو الأطراف السفلية لطفلك خلال ال3 أشهر الماضية؟	**نعم**	**لا**
إذا كانت الإجابة بنعم، يرجى التوضيح		
2.2 هل أخذ طفلك حقن البوتوكس (توكسين البوتولينوم) خلال ال 6 أشهر لماضية؟	**نعم**	**لا**
إذا كانت الإجابة بنعم، يرجى التوضيح		
2.3 هل يعاني طفلك من تشنجات عصبيه (صرع) غير منضبطه ولايمكن التحكم بها؟	**نعم**	**لا**
إذا كانت الإجابة بنعم، يرجى التوضيح		
2.4 هل تعرض طفلك لالتهاب الأذن خلال ال6 أسابيع الماضية؟	**نعم**	**لا**
إذا كانت الإجابة بنعم، يرجى التوضيح		
2.5 هل يعاني طفلك من أي ضعف في السمع؟	**نعم**	**لا**

إذا كانت الإجابة بنعم، يرجى التوضيح		
2.6 هل يعاني طفلك من أي ضعف في البصر, غير لبس النظاره او العدسات ؟	**نعم**	**لا**
إذا كانت الإجابة بنعم، يرجى التوضيح		
2.7 هل يشارك طفلك حاليا في أي دراسات بحثية أخرى؟	**نعم**	**لا**
إذا كانت الإجابة بنعم، يرجى التوضيح		

3. يرجى ملء التفاصيل التالية حول طفلك **:**

3.1 الجنس __________ (ذكر / أنثى **)**

3.2 تاريخ الميلاد _______________ (يوم / شهر / سنة **)**

3.3 العمر __________ سنوات

3.4 كم عدد جلسات العلاج الطبيعي التي يتلقاها طفلك في الأسبوع ________ وكم مده الجلسه الواحده

____

3.5 ما جلسات العلاج الأخرى التي يتلقاها طفلك غيرالعلاج الطبيعي ____________________، __________

كم عدد هذه الجلسات في الأسبوع __________ وكم مده الجلسه الواحده _____________

3.6 إذا كان طفلك يستخدم أداة تساعده على المشي(مثل عكازات, إطار مشي) ما هو نوع هذه الأداة

____

3.7 إذا كان طفلك يستخدم أي جبائر لتقويم الكاحل والقدم أو أي نوع من الأحذية المصممه لطفلك، يرجى إعطاء

تفاصيل_______________

Appendix 32: Participants' attendance sheet

Title of Project: The effect of Wii-Fit balance games on standing postural control in children with cerebral palsy

Name of researcher: Afrah Almuwais

ID Number

Ethics Number: 5520

	Date	Time	Games played (repetition and duration of each game)				Comments
			SH	PS	SS	TT	
Week 1							
First assessment							
Balance measurement 1							
Week 2							
Session 1							
Session 2							
Session 3							
Week 3							
Session 4							
Session 5							
Session 6							
Week 4							
Session 7							
Session 8							
Session 9							
Week 5							
Session 10							
Session 11							
Session 12							
Week 6							
Balance measurement 2							

Appendix 33: Child's attendance sheet (English and Arabic)

The Wii-Fit study attendance sheet

Week 1	First Visit 1  	Balance measurment 2 don't forget you will be vido recorded 	 Now lets play with the Wii Fit
Week 2	1 3	2 4	3 5 
Week 3	1 6	2 7	3 8
Week 4	1 9	2 10	3 11
Week 5	1 12	2 13	3 14  FINISH YAAAY
Week 6	Balance measurement 15  don't forget you will be vido recorded		 

ورقة الحضور لدراسة ألعاب Wii-Fit

الأسبوع 1	أول زيارة 1 	قياس التوازن 2 لا تنسى أنه سيكون هناك كاميرا فيديو 	 هيا نلعب مع Wii Fit
الأسبوع 2	1 3	2 4	3 5 
الأسبوع 3	1 6	2 7	3 8
الأسبوع 4	1 9	2 10	3 11
الأسبوع 5	1 12	2 13	3 14
الأسبوع 6	قياس التوازن 15 لا تنسى أنه سيكون هناك كاميرا فيديو 		انتهى 

Appendix 34: Appendix 1: The child's end of study certificate (English and Arabic)


UNIVERSITY OF Southampton

Certificate of Participation

Awarded to

----

for taking part in the Wii Fit balance games study

Signature

thank you

Date

UNIVERSITY OF Southampton

شهادة شكر

تقدم لالمشارك/او لالمشاركه

لشكره على المشاركه في بحث لدراسة فعالية ألعاب التوازن Wii-Fit

---------------------------- التوقيع

-------------------------- التاريخ

Appendix 35: Paediatric Balance Scale

A

PEDIATRIC BALANCE SCALE

Name: ______________________ Date: ____________

Location: ____________________ Examiner: ____________

Item Description	Score *0 - 4*	Seconds *optional*
1. Sitting to standing	______	
2. Standing to sitting	______	
3. Transfers	______	
4. Standing unsupported	______	______
5. Sitting unsupported	______	______
6. Standing with eyes closed	______	______
7. Standing with feet together	______	______
8. Standing with one foot in front	______	______
9. Standing on one foot	______	______
10. Turning 360 degrees	______	______
11. Turning to look behind	______	
12. Retrieving object from floor	______	
13. Placing alternate foot on stool	______	______
14. Reaching forward with outstretched arm	______	
Total Test Score	______	

General Instructions

1. Demonstrate each task and give instructions as written. A child may receive a practice trial on each item. If the child is unable to complete the task based on their ability to understand the directions, a second practice trial may be given. Verbal and visual directions may be clarified through the use of physical prompts.

2. Each item should be scored utilizing the 0 to 4 scale. Multiple trials are allowed on many of the items. The child's performance should be scored based upon the lowest criteria, which describes the child's best performance. If on the first trial a child receives the maximal score of 4, additional trials need not be administered. Several items require the child to maintain a given position for a specific time. Progressively, more points are deducted if the time or distance requirements are not met; if the subject's performance warrants supervision; or if the subject touches an external support or receives assistance from the examiner. Subjects should understand that they must maintain their balance while attempting the tasks. The choice, of which leg stand on or how far to reach, is left to the subject. Poor judgement will adversely influence the performance and the scoring. In addition to scoring items 4, 5, 6, 7, 8, 9, 10, and 13, the examiner may choose to record the exact time in seconds.

Figure. No caption available.

B

Equipment

The Pediatric Balance Scale was designed to require minimal use of specialized equipment. The following is a complete list of items required for administration of this tool:

adjustable height bench
chair with back support and arm rests
stopwatch or watch with a second hand
masking tape - 1inch wide
a step stool 6 inches in height
chalkboard eraser
ruler or yardstick
a small level

The following items are optional and may be helpful during test administration:
2 child-size footprints
blindfold
a brightly colored object of at least two inches in size
flash cards
2 inches of adhesive-backed hook Velcro
Two 1 foot strips of loop Velcro

****

1. **Sitting To Standing**

* ***Special instruction***: *Items #1 and #2 may be tested simultaneously if, in the determination of the examiner, it will facilitate the best performance of the child.*

INSTRUCTIONS: **Child is asked to "Hold arms up and stand up."** The child is allowed to select the position of his/her arms.

EQUIPMENT: A bench of appropriate height to allow the child's feet to rest supported on the floor with the hips and knees maintained in 90 degrees of flexion.

Best Of Three Trials

( ) 4 able to stand without using hands and stabilize independently
( ) 3 able to stand independently using hands
( ) 2 able to stand using hands after several tries
( ) 1 needs minimal assist to stand or to stabilize
( ) 0 needs moderate or maximal assist to stand

Figure. No caption available.

c

2. **Standing To Sitting**

*** ***Special instruction***: *Items #1 and #2 may be tested simultaneously if, in the determination of the examiner, it will facilitate the best performance of the child.*

INSTRUCTIONS: **Child is asked to sit down slowly, without use of hands.** The child is allowed to select the position of his/her arms.

EQUIPMENT: A bench of appropriate height to allow the child's feet to rest supported on the floor with the hips and knees maintained in 90 degrees of flexion.

Best Of Three Trials

( )4 sits safely with minimal use of hands
( )3 controls descent by using hands
( )2 uses back of legs against chair to control descent
( )1 sits independently, but has uncontrolled descent
( )0 needs assistance to sit

3. **Transfers**

INSTRUCTIONS: Arrange chair(s) for a stand pivot transfer, touching at a forty-five degree angle. **Ask the child to transfer one way toward a seat with armrests and one way toward a seat without armrests.**

Equipment: Two chairs, or one chair and one bench. One seating surface must have armrests. One chair/bench should be of standard adult size and the other should be of an appropriate height to allow the child to conformably sit with feet supported on the floor and ninety degrees of hip and knee flexion.

Best Of Three Trials

( )4 able to transfer safely with minor use of hands
( )3 able to transfer safely; definite need of hands
( )2 able to transfer with verbal cueing and/or supervision (spotting)
( )1 needs one person to assist
( )0 needs two people to assist or supervise (close guard) to be safe

Figure. No caption available.

D

4. **Standing Unsupported**

INSTRUCTIONS: **The child is asked to stand for 30 SECONDS without holding on or moving his/her feet.** A taped line or footprints may be placed on the floor to help the child maintain a stationary foot position. The child may be engaged in non-stressful conversation to maintain attention span for thirty seconds. Weight shifting and equilibrium responses in feet are acceptable; movement of the foot in space (off the support surface) indicates end of the timed trial.

EQUIPMENT: a stop watch or watch with a second hand
a twelve inch long masking tape line or two footprints placed shoulder width apart

( ) 4 able to stand safely 30 SECONDS
( ) 3 able to stand 30 SECONDS with supervision (spotting)
( ) 2 able to stand 15 SECONDS unsupported
( ) 1 needs several tries to stand 10 SECONDS unsupported
( ) 0 unable to stand 10 SECONDS unassisted

_____Time in seconds

Special Instructions: If a subject is able to stand 30 SECONDS unsupported, score full points for sitting unsupported. Proceed to item #6

5. **Sitting With Back Unsupported And Feet Supported On The Floor**

INSTRUCTIONS: **Please sit with arms folded on your chest for 30 SECONDS**. Child may be engaged in non-stressful conversation to maintain attention span for thirty seconds. Time should be stopped if protective reactions are observed in trunk or upper extremities.

EQUIPMENT: a stop watch or watch with a second hand
a bench of appropriate height to allow the feet to rest supported on the floor with the hips and knees maintained in ninety degrees of flexion.

( ) 4 able to sit safely and securely 30 SECONDS
( ) 3 able to sit 30 SECONDS under supervision (spotting) or may require definite use of upper extremities to maintain sitting position
( ) 2 able to sit 15 SECONDS
( ) 1 able to sit 10 SECONDS
( ) 0 unable to sit 10 SECONDS without support

_____ Time in seconds

Figure. No caption available.

E

6. **Standing Unsupported With Eyes Closed**

INSTRUCTIONS: The child is asked to stand still with feet shoulder width apart and close his/her eyes for ten seconds. **Direction: "When I say close your eyes, I want you to stand still, close your eyes, and keep them closed until I say open."** If necessary, a blindfold may be used. Weight shifting and equilibrium responses in the feet are acceptable; movement of the foot in space (off the support surface) indicates end of timed trial. A taped line or footprints may be placed on the floor to help the child maintain a stationary foot position.

EQUIPMENT: a stop watch or watch with a second hand
a twelve-inch long masking tape line or two footprints placed shoulder width apart
blindfold

Best Of 3 Trials,

( ) 4 able to stand 10 seconds safely
( ) 3 able to stand 10 seconds with supervision (spotting)
( ) 2 able to stand 3 seconds
( ) 1 unable to keep eyes closed 3 seconds but stays steady
( ) 0 needs help to keep from falling

____ **Time in seconds**

7. **Standing Unsupported With Feet Together**

INSTRUCTIONS: **The child is asked to place his/her feet together and stand still without holding on.** The child may be engaged in non-stressful conversation to maintain attention span for thirty seconds. Weight shifting and equilibrium responses in feet are acceptable; movement of the foot in space (off the support surface) indicates end of timed trial. A taped line or footprints may be placed on the floor to help the child maintain stationary foot position.

EQUIPMENT: a stop watch or watch with a second hand
a twelve inch long masking tape line or two footprints placed together

Best Of 3 Trials

( ) 4 able to place feet together independently and stand 30 seconds safely
( ) 3 able to place feet together independently and stand for 30 seconds with supervision (spotting)
( ) 2 able to place feet together independently but unable to hold for 30 seconds
( ) 1 needs help to attain position but able to stand 30 seconds with feet together
( ) 0 needs help to attain position and/or unable to hold for 30 seconds

____ **Time in seconds**

Figure. No caption available.

F

8. **Standing Unsupported One Foot In Front**

INSTRUCTIONS: **The child is asked to stand with one foot in front of the other, heel to toe.** If the child cannot place feet in a tandem position (directly in front), they should be asked to step forward far enough to allow the heel of one foot to be placed ahead of the toes of the stationary foot. A taped line and/or footprints may be placed on the floor to help the child maintain a stationary foot position. In addition to a visual demonstration, a single physical prompt (assistance with placement) may be given. The child may be engaged in non-stressful conversation to maintain his/her attention span for 30 seconds. Weight shifting and/or equilibrium reactions in the feet are acceptable. Timed trials should be stopped if either foot moves in space (leaves the support surface) and/or upper extremities support is utilized.

EQUIPMENT: a stop watch or watch with a second hand
a twelve inch long masking tape line or two footprints placed heel to toe

Best Of Three Trials

( ) 4 able to place feet tandem independently and hold 30 seconds
( ) 3 able to place foot ahead of other independently and hold 30 seconds. *Note*: The length of the step must exceed the length of the stationary foot and the width of the stance should approximate the subject's normal stride width.
( ) 2 able to take small step independently and hold 30 seconds, or required assistance to place foot in front, but can stand for 30 seconds.
( ) 1 needs help to step, but can hold 15 seconds
( ) 0 loses balance while stepping or standing

_____ **Time in seconds**

9. **Standing On One Leg**

INSTRUCTIONS: **The child is asked to stand on one leg for as long as he/she is able to without holding on.** If necessary the child can be instructed to maintain his/her arms (hands) on his/her hips (waist). A taped line or footprints may be placed on the floor to help the child maintain a stationary foot position. Weight shifting and/or equilibrium reactions in the feet are acceptable. Timed trials should be stopped if the weight-bearing foot moves in space (leaves the support surface), the up limb touches the opposite leg or the support surface and/or upper extremities are utilized for support.

EQUIPMENT: a stop watch or watch with a second hand
a twelve inch long masking tape line or two footprints placed heel to toe

3 Trials Average Score

( ) 4 able to lift leg independently and hold 10 seconds
( ) 3 able to lift leg independently and hold 5 to 9 seconds
( ) 2 able to lift leg independently and hold 3 to 4 seconds
( ) 1 tries to lift leg; unable to hold 3 seconds but remains standing
( ) 0 unable to try or needs assist to prevent fall

Figure. No caption available.

G

10. **Turn 360 Degrees**

INSTRUCTIONS: **The child is asked to turn completely around in a full circle, STOP, and then turn a full circle in the other direction.**

EQUIPMENT: A stop watch or watch with a second hand

( ) 4 able to turn 360 degrees safely in 4 seconds or less each way (total of less than eight seconds)
( ) 3 able to turn 360 degrees safely in one direction only in 4 seconds or less completes turn in other direction requires more than four seconds
( ) 2 able to turn 360 degrees safely but slowly
( ) 1 needs close supervision (spotting) or constant verbal cueing
( ) 0 needs assistance while turning

_____ **Time in seconds**

11. **Turning To Look Behind Left & Right Shoulders While Standing Still**

INSTRUCTIONS: **The child is asked to stand with his/her feet still, fixed in one place. "Follow this object as I move it. Keep watching it as I move it, but don't move your feet."**

EQUIPMENT: a brightly colored object of at least two inches in size, or flash cards
a twelve inch long masking tape line or two footprints placed shoulder width apart

( ) 4 looks behind/over each shoulder; weight shifts include trunk rotation
( ) 3 looks behind/over one shoulder with trunk rotation; weight shift in the opposite direction is to the level of the shoulder; no trunk rotation
( ) 2 turns head to look to level of shoulder; no trunk rotation
( ) 1 needs supervision (spotting) when turning; the chin moves greater than half the distance to the shoulder
( ) 0 needs assist to keep from losing balance or falling; movement of the chin is less than half the distance to the shoulder

12. **Pick Up Object From The Floor From A Standing Position**

INSTRUCTIONS: **The child is asked to pick up a chalkboard eraser placed approximately the length of his/her foot in front of his/her dominant foot.** In children, where dominance is not clear, ask the child which hand they want to use and place the object in front of that foot.

EQUIPMENT: a chalkboard eraser
a taped line or footprints

( ) 4 able to pick up an eraser safetly and easily
( ) 3 able to pick up eraser but needs supervision (spotting)
( ) 2 unable to pick up eraser but reaches 1 to 2 nches from eraser and keeps balance independently
( ) 1 unable to pick up eraser; needs supervision (spotting) while attempting
( ) 0 unable to try, needs assist to keep from losing balance or falling

Figure. No caption available.

H

13. **Placing Alternate Foot On Step Stool While Standing Unsupported**

INSTRUCTIONS: **The child is asked to place each foot alternately on the step stool and to continue until each foot has touched the step/stool four times.**

EQUIPMENT: a step/stool of four inches in height
a stop watch or watch with a second hand.

( ) 4 stands independently and safely and completes 8 steps in 20 seconds
( ) 3 able to stand independently and complete 8 steps >20 seconds
( ) 2 able to complete 4 steps without assistance, but requires close supervision (spotting)
( ) 1 able to complete 2 steps; needs minimal assistance
( ) 0 needs assistance to maintain balance or keep from falling, unable to try

____ **Time in seconds**

14. **Reaching Forward With Outstretched Arm While Standing**

General Instruction And Set Up: A yardstick affixed to a wall via Velcro strips will be used as the measuring tool. A taped line and/or footprints are used to maintain a stationary foot position. The child will be asked to reach as far forward without falling, and without stepping over the line. The MCP joint of the child's fisted hand will be used as the anatomical reference point for measurements. Assistance may be given to initially position the child's arm at 90 degrees. Support may not be provided during the reaching process. If 90 degrees of shoulder flexion cannot be obtained, then this item should be omitted.

INSTRUCTIONS: **The child is asked to lift his/her arm up like this. "Stretch out your fingers, make a fist, and reach forward as far as you can without moving your feet."**

3 Trials Average Results

EQUIPMENT: a yardstick or ruler
a taped line or footprints
a level

( ) 4 can reach forward confidently >10 inches
( ) 3 can reach forward >5 inches, safely
( ) 2 can reach forward >2 inches, safely
( ) 1 reaches forward but needs supervision (spotting)
( ) 0 loses balance while trying, requires external support

____ **Total Test Score**
Maximum Score = 56

Figure. No caption available.

Appendix 36: The Physical Activity Enjoyment Scale (English and Arabic)

The Physical Activity Enjoyment Scale form for children

Title of Project: The effect of Wii-Fit balance games on standing postural control in children with cerebral palsy

Name of researcher: Afrah Almuwais

Ethics Number: 5520

ID Number ☐☐☐

When I am playing Wii-fit games . . .

	1 Disagree a  lot	2	3	4	5 Agree a lot 
1. I enjoy it					
2. I feel bored					
3. I dislike it					
4. I find it pleasurable					
5. It's no fun at all					
6. It gives me energy					
7. It makes me sad					
8. It's very pleasant					
9. My body feels good					
10. I get something out of it					
11. It's very exciting					
12. It frustrates me					
13. It's not at all interesting					
14. It gives me a strong feeling of success					
15. It feels good					
16. I feel as though I would rather be doing something else					

عنوان الدراسة: تأثير العاب التوازن (Wii-Fit) على الأطفال المصابين بالشلل الدماغي

الباحثه: أفراح المويس

البحث رقم: 5520

ID Number

عندما ألعب بألعاب (Wii-Fit) ....

	1 غير موافق  بشده	2	3	4	5 موافق بشده 
1. أنا أستمتع بها					
2. أشعر بالملل					
3. لم تعجبني					
4. أجدها ممتعة					
5. انها ليست متعة على الإطلاق					
6. انها تعطيني طاقة					
7. تحزنني					
8. انها ممتعة للغاية					
9. أشعر أن جسمي جيد					
10. إستفدت منها					
11. انها محمسة للغاية					
12. إنها تحبطني (تسبب الإحباط)					
13. انها ليست مثيرة للاهتمام على الإطلاق					
14. انها تعطيني شعور قوي بالنجاح					
15. إنه شعور جيد					
16. أشعر أنه أفضل أن أفعل شيئا آخر					

Appendix 37: Table of the row results data for analysis in chapter 6 and 7

Table A37.1: The row data of COP length for reliability between two baselines and the difference between pre- and post-training

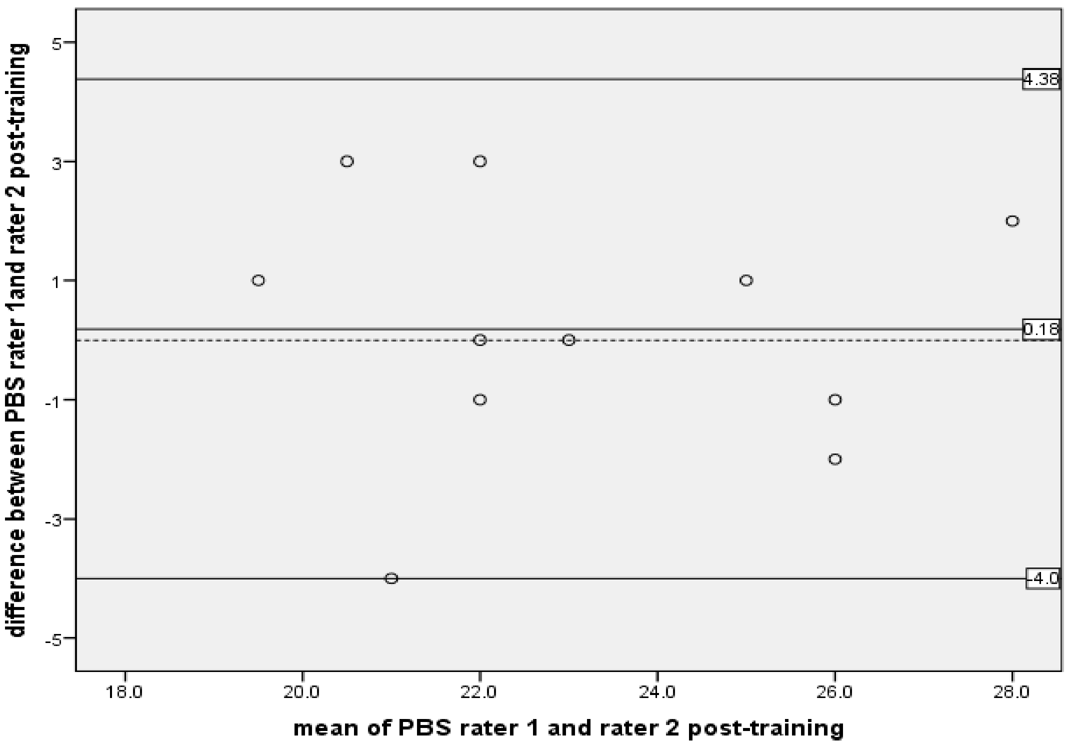
ID	Day 1								Day 2								Day 3							
	EO			Mean	EC			Mean	EO			Mean	EC			Mean	EO			Mean	EC			Mean
	1	2	3		1	2	3		1	2	3		1	2	3		1	2	3		1	2	3	
1	3.45	3.29	3.85	3.53	3.68	3.8	6.56	4.68	3.68	3.54	3.83	3.68	3.57	3.34	3.53	3.48		5.39		5.39	4.24	7.92	4.23	5.46
2	3.22	3.53	3.24	3.33	4.17	4.23	4.13	4.18	3.47	4.25	4.95	4.22	5.4	7.61		6.51								
3	2.44	2.72	2.67	2.61	2.62	3.2	3.09	2.97	2.25	2.43	2.71	2.46	3.73	2.85	2.9	3.16	2.64	3.29	4.96	3.63	3.26	2.96	2.85	3.02
4	2.37	1.98	1.97	2.11	3.68	2.72	2.21	2.87	2.05	2.07	1.85	1.99	3.11	4.86	2.44	3.47	1.97	2.81	2.35	2.38	2.92	2.96	2.81	2.9
5	2.42	3.61		3.02	3.56	3.46		3.51	2.67	3.35	2.38	2.8	4.79	3.87	4.05	4.24	3.21	2.39	2.67	2.76	1.84	2.06	4.05	2.65
6	4.29	4.24	4.49	4.34	3.83	4.28	5.39	4.5	4.7	4.87	3.81	4.46	7.22	3.56	4.14	4.97	4.31	3.52	4.53	4.12	3.93	4.69	4.2	4.27
7	4.15	4.25	4.16	4.19	4.21	4.13	4.1	4.15	3.61	3.75	4.31	3.89	4.1	3.79	3.96	3.95	3.66	3.97	4.22	3.95	4.22	4.05	4.52	4.26
8	3.6	3.53	3.92	3.68	4.04	3.79	4.05	3.96	4.13	3.91	4	4.01	4.5	4.37	4.17	4.35	3.87	3.76	4.16	3.93	3.96	4.13	4.35	4.15
9	2.31	2.26	2.53	2.37	2.49	2.81	2.73	2.68	2.79	2.46	2.72	2.66	3.49	3.18	3.39	3.35	2.97	3.4	4.09	3.49	3.28	3.36	2.92	3.19
10	1.63	2.28	2.26	2.06	2.08	1.69	2	1.92	1.83	2.43	1.95	2.07	1.68	1.78	2.04	1.83	2.71	1.54	1.63	1.96	1.78	1.62	1.79	1.73
11	3.75	4	4.78	4.18	3.79	4.6	3.35	3.91	4.7	4.53	5.04	4.76	5.52	6.07	5.45	5.68	9.27	11.19	8.33	9.6	9.84	11.5	10.08	10.47
12	3.89	4.96	4.19	4.35	4.43	4.54	4.94	4.64	4.46	5.27	4.87	4.87	3.7	4.19	4.94	4.28	4.55	4.66	4.75	4.65	3.79	3.99	3.96	3.91

Table A37.2: row data for PBS total scores between rateres

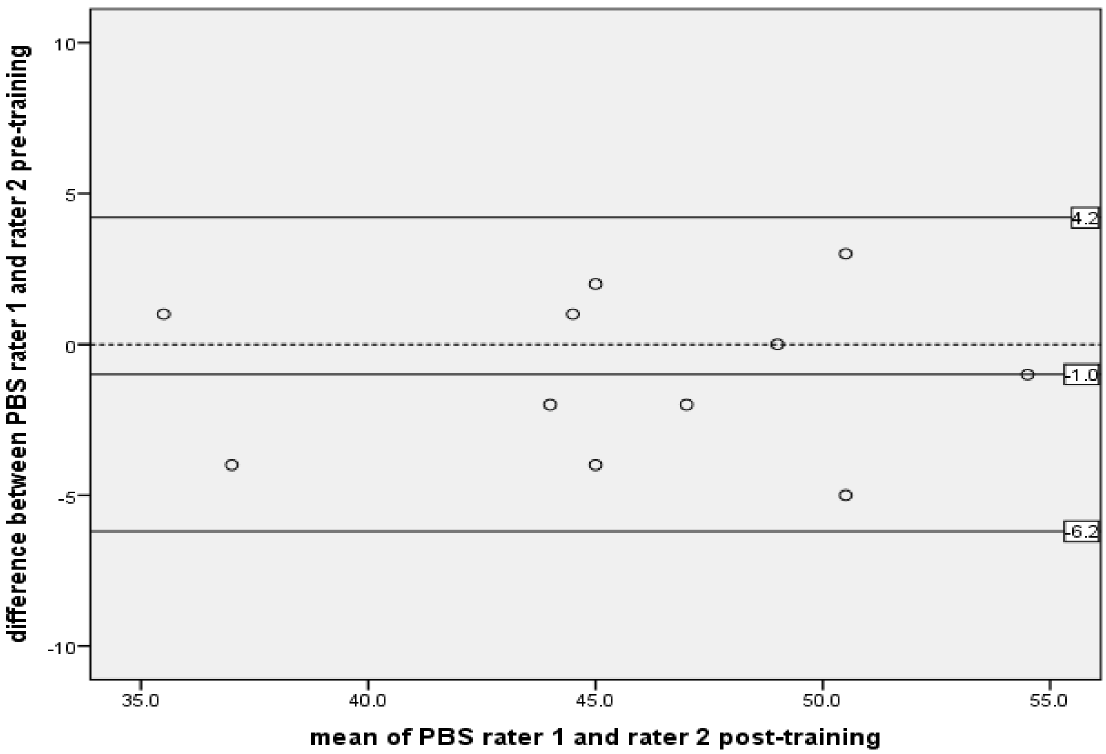
ID	Pre-training		Difference	Mean	Post-training		Difference	Mean
	Rater 1	Rater 2			Rater 1	Rater 2		
1	43	45	-2	44	44	41	3	22
2	50			50				
3	49	49	0	49	52	54	-2	26
4	52	49	3	50.5	52	53	-1	26
5	36	35	1	35.5	39	36	3	19.5
6	48	53	-5	50.5	50	49	1	25
7	46	48	-2	47	46	46	0	23
8	45	44	1	44.5	44	45	-1	22
9	54	55	-1	54.5	56	54	2	28
10	43	47	-4	45	42	46	-4	21
11	35	39	-4	37	39	38	1	19.5
12	46	44	2	45	44	44	0	22

Table A37.3: the agreement between PBS raters using ICC 3,2

	Raters	Mean	SD	ICC 3,2	lower CI	upper CI	SEM
Pre-training	1	45.18	5.88	0.892	0.66	0.97	1.89
	2	46.18	5.76				
Post-training	1	46.18	5.6	0.857	0.57	0.96	2.47
	2	45.36	7.51				



A.(Pre-training)



B.(Post-training)

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