The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

University of Cape Town

The effect of the Nintendo Wii Fit on the balance control and gross motor function of children with spastic hemiplegic cerebral palsy

By:
Marieke Daniela Pronk
UCT Student Number: PRNMAR011

Submitted in fulfillment of the requirements for the degree of MSc in Physiotherapy by dissertation.

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
School of Health and Rehabilitation Sciences
Division of Physiotherapy

Supervisor:
Prof. Jennifer Jelsma
PhD Physiotherapy
University of Cape Town, School of Health and Rehabilitation Sciences,
Division of Physiotherapy

Co-Supervisors:
Dorothee Jelsma
MPPT Physiotherapy
Avans and University of Professionals, Breda, Netherlands

Gillian Ferguson
MSc Physiotherapy
University of Cape Town, School of Health and Rehabilitation Sciences,
Division of Physiotherapy

November 2010

University of Cape Town

Declaration

I, Marieke Daniela Praak.. hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

I empower the university to reproduce for the purpose of research either the whole or any portion of the contents in any manner whatsoever.

Signature: Signed by candidate

Date: ...29.04.2011.....

Acknowledgements

The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF.

My sincerest gratitude goes out to the following people:

The children who participated in this study: their enthusiasm, playful nature and enjoyment were a great inspiration to me throughout this project.

The parents of the children who participated in this study: for having an open mind and providing their consent. It takes a progressive outlook and a leap of faith to consent to video gaming during school time!

The school physiotherapists and physiotherapy students: for their help in carrying out the intervention during this study. Your contribution greatly improved the quality of this research project. Special thanks go to Heidi van den Berg for keeping track of the proceedings at School 1. I truly valued your efficiency, tremendous input and enthusiasm during the data collection period.

Pamela Versveld, who was instrumental in teaching me about task-orientated and goal-directed learning. The information you shared with me from your extensive experience in paediatric neurology has profoundly influenced my thinking. I am grateful that you were willing to share your wisdom so freely and generously.

University of Cape Town

My co-supervisors Dorothee Jelsma and Gillian Ferguson, who spent many hours reading through drafts and making helpful suggestions and contributions to this research project. Special thanks go to Gill for lending an ear and encouraging me through the tough times. I always tried to keep your wise words in mind: "It's a marathon, not a sprint!".

My supervisor Professor Jennifer Jelsma: Thank you for your kindness and patience in times when frustration and impatience would have been the more appropriate response. I appreciated your sense of humor and your calm, reassuring nature throughout this process. I feel privileged to have had the guidance of such a great researcher!

My dear friend Karen Tien, who provided me the emotional support only a true friend can give. Thank you my sisi! You will be a great doctor some day.

My love, Kirby Mackintosh, who assisted with the grammar and sentence construction. You are such a blessing in my life (for reasons other than your linguistic prowess).

My mother Heidi, who supplied wisdom and comic relief when I needed it.

Most importantly, my father Willem, who believes that education is priceless! Thank you for affording me the opportunity to further my studies. I value the safety you provide for me with your unconditional love and support.

University of Cape Town

Executive Summary

Key words: balance, postural control, hemiplegia, cerebral palsy, intervention, rehabilitation, physiotherapy, Nintendo Wii Fit

Background: Balance and postural control are an integral part of gross motor function in activities of daily living. Studies have shown that children with hemiplegic cerebral palsy have poor directional specificity as well as problems with the temporal and spatial modulation of appropriate muscle action in response to balance perturbations. Children with hemiplegia have also been shown to develop direction-specific postural control at a slower pace than typically developing children. Apart from their postural muscle co-ordination problems, these children have difficulties with sensory integration which contributes to increased reaction time. Research on balance training in children with cerebral palsy has demonstrated that improved balance translates into more effective gross motor function. It appears that postural control mechanisms are still modifiable for children with cerebral palsy even in elementary to middle school ages. Physiotherapy treatment for children with cerebral palsy should therefore involve balance training as a focus of intervention. Literature on balance control and virtual reality rehabilitation justifies investigating the use of a commercially available gaming system, such as the Nintendo Wii Fit, as a rehabilitation tool to improve balance control and therefore gross motor function in children with cerebral palsy. **Objective:** To determine the effect of an intervention with the Nintendo Wii Fit on the balance control and gross motor function of children with spastic hemiplegic cerebral palsy. **Design:** An AB, single-subject research design with multiple subjects, using repeated measures and multiple baselines was utilised. **Setting:** Two special-needs schools in Cape Town, South Africa. **Participants:** Fourteen children aged 7-14 years with spastic hemiplegic cerebral palsy (GMFCS Level I and II). **Intervention:** The regular physiotherapy regime of the participants was substituted with three weeks of intensive therapy consisting of four Wii Fit sessions per week (4 x 25 minute sessions = 100 minutes on the Wii Fit per week).

University of Cape Town

Outcome Measures: The outcome measures consisted of: a set of adapted, criterion-referenced activities based on the Bruininks-Oseretsky Test of Motor Proficiency 2nd Edition (BOT-2) Subtests 5 (Balance) and 6 (Running Speed and Agility) to measure balance and gross motor function-; the Timed Up and Down Stairs test (TUDS) to measure functional mobility; and the EQ-5D-Y Visual Analogue Scale to measure health-related quality of life. **Method:** Children were divided into four groups of three or four. One group was treated per school term over the course of four school terms. A three week baseline measure was taken whereupon two children started the intervention in the third week. Once the first two children had completed the intervention, the remaining two children commenced the intervention allowing for multiple, staggered baselines. A single-blind protocol was implemented in that the assessor was unaware of the phase of intervention each child was in. Physiotherapists at the relevant schools randomised participants to treatment groups and carried out interventions on behalf of the researcher. The blinded researcher assessed all four children once a week over a period of nine weeks. These weekly measures allowed for regular monitoring of changes in outcome measures and participants acted as their own controls. Inferences about treatment effectiveness were made by using the Non-overlap of all Pairs (NAP) method of statistical analysis between baseline and intervention phases. Graphs were visually analysed for changes in trend and their correspondence to the onset of intervention. A two month post-intervention assessment allowed the researcher to establish whether possible improvements were retained. **Results:** 11 of the 14 children under investigation demonstrated medium to large improvements in balance control during and post Wii Fit intervention. These gains in balance control were retained 2 months after intervention cessation. Results for the Running Speed and Agility, TUDS and EQ-5D-Y VAS measures were more variable and did not demonstrate significant and consistent improvements. **Conclusion:** It was found that the Nintendo Wii Fit had potentially beneficial effects on the balance control of 11 of the 14 children under investigation. As a result it may be considered a useful rehabilitation tool to improve the balance control of children with spastic hemiplegic cerebral palsy. Although a trend towards improvement was seen in running speed and agility, this was not significant. The lack of carry-over from Wii Fit gaming skill to functional mobility may have been due to the

University of Cape Town

brevity of the intervention as well as a lack of transferability of the dynamic balance skills gained during Wii Fit gaming. The concept of Wii Fit gaming as a form of therapy is consistent with the paradigm shift towards task orientated and goal directed learning that has been taking place in physiotherapy over the past few decades. Future studies should include larger subject numbers, control groups and longer intervention periods.

University of Cape Town

University of Cape Town

Table of Contents

Declaration ii

Acknowledgements iv

Executive Summary vi

Table of Contents x

List of Tables xvi

List of Figures xviii

Glossary of abbreviated terms xx

1. Introduction 1

1.1 Background 1

1.2 Aim and Objectives 4

1.2.1 Aim 5

1.2.2 Specific Objectives 5

1.3 Research question 5

1.4 Significance of the study 6

2. Literature Review 9

2.1 Introduction 9

2.2 The epidemiology of cerebral palsy and congenital hemiplegia 10

2.2.1 Incidence and Prevalence 10

2.2.2 Classification 11

2.2.3 Diagnosis 14

2.2.4 Aetiology 15

2.3 Manifestations of cerebral palsy with particular emphasis on congenital hemiplegia 17

2.3.1 Impairments 17

2.3.2 Mobility and Activity limitations 24

University of Cape Town

2.3.3 Participation restrictions *27*

2.4 Motor learning, postural control and physiotherapy treatment of children with hemiplegic cerebral palsy 28

2.4.1 Motor learning: neural plasticity and brain reorganisation *28*

2.4.2 Postural control: development and impact on movement *32*

2.4.3 Physiotherapy interventions to improve postural control *37*

2.4.4 The Nintendo Wii Fit balance board as a rehabilitation tool *41*

2.4.5 Practice schedules: frequency and structure of therapy *49*

2.5 Outcome measures 53

2.5.1 Classification and Psychometric properties *53*

2.5.2 Measuring Impairment *54*

2.5.3 Measuring Gross Motor Function *64*

2.5.4 Measuring Health-Related Quality of Life *69*

2.6 Study designs 70

2.7 Statistical analysis 72

2.8 Conclusion based on the literature review 76

3. Methodology 79

3.1 Research design 79

3.2 Null hypothesis 80

3.3 Participants 80

3.4 Eligibility criteria 83

3.4.1 Inclusion criteria *83*

3.4.2 Exclusion criteria *83*

3.5 Sample size 84

3.6 Instrumentation 85

3.6.1 Functional Mobility: The Timed Up and Down Stairs test *85*

3.6.2 Balance and Gross Motor Function: The Bruininks-Oseretsky Test of Motor Proficiency (BOT-2) *86*

3.6.3 Weight Distribution: The Wii Fit body test *90*

3.6.4 Spasticity and Muscle Tone: The Modified Ashworth Scale *91*

University of Cape Town

3.6.5 Joint Range of Motion: Goniometry *91*

3.6.6 Health Related Quality of Life: The EQ-5D-Y VAS *91*

3.6.7 Inter-rater reliability in performing the outcome measures *92*

3.7 Procedure 97

3.7.1 Assessing the feasibility of this study *97*

3.7.2 Research setting *98*

3.7.3 Gaining access *98*

3.7.4 Preparation and training of research assistants *99*

3.7.5 Treatment and measurement *100*

3.7.6 Data management *105*

3.8 Statistical analysis 106

3.9 Ethical considerations 108

3.9.1 Beneficence *108*

3.9.2 Nonmaleficence *109*

3.9.3 Autonomy *111*

3.9.4 Confidentiality *111*

3.9.5 Declaration of Helsinki *112*

4. Results 115

4.1 Participant characteristics 115

4.1.1 Demographic details *115*

4.1.2 Medical History *116*

4.1.3 MAS measures *118*

4.2 Wii fit training results 119

4.2.1 Wii Training Time *119*

4.2.2 Individual Results *120*

4.2.3 Treatment effect *142*

4.2.4 Post-hoc analysis of treatment effect *143*

4.2.5 Variables related to Improvement *146*

University of Cape Town

4.2.6 Gaming Score *149*

4.2.7 Therapy preference *151*

5. Discussion 153

5.1 Sample 154

5.2 Individual outcome measure results 154

5.2.1 Balance *154*

5.2.2 Running Speed and Agility *158*

5.2.3 TUDS *161*

5.2.4 The VAS of the EQ-5D-Y *163*

5.2.5 Two month post intervention cessation measurement *164*

5.2.6 Additional remarks *165*

5.3 Limitations 166

5.3.1 Limitations in the study sample and study design *166*

5.3.2 Limitations in the instrumentation chosen *168*

5.3.3 Limitations in the intervention schedule *170*

5.3.4 Limitations in the statistical analysis *171*

5.3.5 General Limitations *171*

5.4 Recommendations for Wii Fit applications and future studies 172

6. Conclusion 177

7. References 181

8. Appendices 201

8.1 Surgical and non-surgical treatment of children with spastic hemiplegic cerebral palsy 203

8.1.1 Tenotomies *203*

8.1.2 Selective Dorsal Rhizotomies *204*

8.1.3 Botox *204*

8.1.4 Casting *205*

8.1.5 Ankle-Foot Orthoses *206*

8.1.6 Upper limb orthoses *206*

University of Cape Town

University of Cape Town

List of Tables

Table 1: GMFCS Level descriptors 13

Table 2: Summary of Balance tests 60

Table 3: Adapted Version of Subtest 5: Balance of the BOT-2 (children with hemiplegia) 88

Table 4: Inter-rater reliability for the MAS scores of the Quadriceps muscle group 93

Table 5: Inter-rater reliability for the MAS scores of the Hamstring muscle group 93

Table 6: Inter-rater reliability for the MAS scores of the Triceps surae muscle group 94

Table 7: Intervention Schedule 101

Table 8: Child 1-14 Demographic and Academic information 116

Table 9: Child 1-14 Medical Information 117

Table 10: Child 1-14 MAS scores and Joint contractures 118

Table 11: Total Wii Fit training time 119

Table 12: Child 1 Balance, Running Speed and Agility TUDS and VAS scores 120

Table 13: Child 1 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.... 121

Table 14: Child 2 Balance, Running Speed and Agility, TUDS and VAS scores 122

Table 15: Child 2 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.... 122

Table 16: Child 3 Balance, Running Speed and Agility, TUDS and VAS scores 123

Table 17: Child 3 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.... 124

Table 18: Child 4 Balance, Running Speed and Agility, TUDS and VAS scores 125

Table 19: Child 4 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.... 125

Table 20: Child 5 Balance, Running Speed and Agility, TUDS and VAS scores 126

Table 21: Child 5 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.... 127

Table 22: Child 6 Balance, Running Speed and Agility, TUDS and VAS scores 128

Table 23: Child 6 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.... 129

Table 24: Child 7 Balance, Running Speed and Agility, TUDS and VAS scores 130

Table 25: Child 7 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.... 130

Table 26: Child 8 Balance, Running Speed and Agility, TUDS and VAS scores 131

University of Cape Town

Table 27: Child 8 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.... 132
Table 28: Child 9 Balance, Running Speed and Agility, TUDS and VAS scores.... 133
Table 29: Child 9 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.... 133
Table 30: Child 10 Balance, Running Speed and Agility, TUDS and VAS scores.... 134
Table 31: Child 10 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.. 135
Table 32: Child 11 Balance, Running Speed and Agility, TUDS and VAS scores.... 136
Table 33: Child 11 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.. 136
Table 34: Child 12 Balance, Running Speed and Agility, TUDS and VAS scores.... 137
Table 35: Child 12 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.. 138
Table 36: Child 13 Balance, Running Speed and Agility, TUDS and VAS scores.... 139
Table 37: Child 13 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.. 140
Table 38: Child 14 Balance, Running Speed and Agility, TUDS and VAS scores.... 141
Table 39: Child 14 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS.. 141
Table 40: Treatment effect sizes 142
Table 41: Friedman's ANOVA for the Balance Score.... 143
Table 42: Post-hoc analysis of Balance scores.... 144
Table 43: Friedman's ANOVA for the Running Speed and Agility scores 145
Table 44: Friedman's ANOVA for the TUDS scores 145
Table 45: Friedman's ANOVA for the VAS scores 146
Table 46: Spearman's Rank Order correlation for Balance score difference and Wii Fit training time.... 146
Table 47: Cross-tabulation of Running Speed and Agility and Academic Achievement.... 147
Table 48: Chi-Square analysis of Running Speed and Agility and Academic Achievement.... 147
Table 49: Cross-tabulaton of TUDS and AFO.... 148
Table 50: Chi-Square analysis of TUDS and AFO 148
Table 51: Cross-tabulation of Balance and Running Speed and Agility score outcomes 148
Table 52: Wilcoxon matched pairs test of First and Last Bubble game scores 149
Table 53: Spearman's Rank Order correlation of Bubble game score and Balance score 150
Table 54: Individual therapy preferences.... 151

University of Cape Town

List of Figures

Figure 1: Nintendo Wii Fit balance board 42

Figure 2: Nintendo Wii Soccer – force plates translate COP changes into movement of the Avatar 52

Figure 3: Participant sampling and grouping at School 1 and School 2 83

Figure 4: Child 1 Balance, Running Speed and Agility and TUDS 120

Figure 5: Child 2 Balance Running Speed and Agility and TUDS 122

Figure 6: Child 3 Balance, Running Speed and Agility and TUDS 123

Figure 7: Child 4 Balance, Running Speed and Agility and TUDS 125

Figure 8: Child 5 Balance, Running Speed and Agility and TUDS scores 127

Figure 9: Child 6 Balance, Running Speed and Agility and TUDS 128

Figure 10: Child 7 Balance, Running Speed and Agility and TUDS 130

Figure 11: Child 8 Balance, Running Speed and Agility and TUDS 131

Figure 12: Child 9 Balance, Running Speed and Agility and TUDS 133

Figure 13: Child 10 Balance, Running Speed and Agility and TUDS 135

Figure 14: Child 11 Balance, Running Speed and Agility and TUDS 136

Figure 15: Child 12 Balance, Running Speed and Agility and TUDS 138

Figure 16: Child 13 Balance, Running Speed and Agility and TUDS 139

Figure 17: Child 14 Balance, Running Speed and Agility and TUDS 141

Figure 18: Box and Whisker plot of Friedman's ANOVA for Balance scores 144

Figure 19: Box and Whisker plot of Bubble game scores (first and last session) 150

University of Cape Town

University of Cape Town

Glossary of abbreviated terms

AUC: Area under the curve refers to the area under the receiver operator characteristic (ROC) curve, also known as the "sensitivity and specificity curve", for detailing error types[1].

BBS: The Berg Balance Scale is a performance based scale that was developed to assess balance in elderly or neurologically impaired subjects [2]. The BBS is performance based and has 14 items. 1) sitting to standing 2) standing unsupported 3) sitting unsupported 4) standing to sitting 5) transfers 6) standing with eyes closed 7) standing with feet together 8) reaching forward with outstretched arm 9) retrieving object from floor 10) turning to look behind 11) turning 360 degrees 12) placing alternate foot on stool 13) standing with one foot in front 14) standing on one foot [3].

BOT-2: Bruininks-Oseretsky Test 2 is the second and latest edition of the Bruininks-Oseretsky Test of Motor Proficiency – see below.

BOTMP: The Bruininks-Oseretsky Test of Motor Proficiency was developed as a norm-referenced test for typically developing children between the ages of 4.5-14.5 years. The BOT-2 has been used as an evaluative and discriminative test in several studies investigating motor performance and efficacy of interventions in child population groups with a range of disabilities, including CP [4 5] .

CIMT: Constraint induced movement therapy is a form of therapy used for the treatment of hemiplegic patients. It involves an intensive period of massed practice over a short period of time. The patient is required to wear a restraining device (mitt, cast, splint, sling) to prevent use of the unaffected upper limb during therapy. Intensive

University of Cape Town

Glossary of abbreviated terms

AUC: Area under the curve refers to the area under the receiver operator characteristic (ROC) curve, also known as the "sensitivity and specificity curve", for detailing error types[1].

BBS: The Berg Balance Scale is a performance based scale that was developed to assess balance in elderly or neurologically impaired subjects [2]. The BBS is performance based and has 14 items. 1) sitting to standing 2) standing unsupported 3) sitting unsupported 4) standing to sitting 5) transfers 6) standing with eyes closed 7) standing with feet together 8) reaching forward with outstretched arm 9) retrieving object from floor 10) turning to look behind 11) turning 360 degrees 12) placing alternate foot on stool 13) standing with one foot in front 14) standing on one foot [3].

BOT-2: Bruininks-Oseretsky Test 2 is the second and latest edition of the Bruininks-Oseretsky Test of Motor Proficiency – see below.

BOTMP: The Bruininks-Oseretsky Test of Motor Proficiency was developed as a norm-referenced test for typically developing children between the ages of 4.5-14.5 years. The BOT-2 has been used as an evaluative and discriminative test in several studies investigating motor performance and efficacy of interventions in child population groups with a range of disabilities, including CP [4 5] .

CIMT: Constraint induced movement therapy is a form of therapy used for the treatment of hemiplegic patients. It involves an intensive period of massed practice over a short period of time. The patient is required to wear a restraining device (mitt, cast, splint, sling) to prevent use of the unaffected upper limb during therapy. Intensive

University of Cape Town

repetition of movement with the affected upper limb has been shown to stimulate the emergence of new motor skills [6].

CP: "Cerebral Palsy describes a group of developmental disorders of movement and posture, causing activity restrictions and disability that are attributed to disturbances occurring in the foetal or infant brain. The motor impairment may be accompanied by a seizure disorder and by impairment of sensation, cognition, communication, and/or behaviour" [7].

COM: Centre of Mass is a point derived from the weighted average of each body segment, and moves when the body segments change position [8].

COP: Centre of Pressure is the point where the resultant force vector of ground reaction forces from the supporting surface is applied to the body [8].

DCD: "Developmental Coordination Disorder, a chronic and usually permanent condition found in children, is characterized by motor impairment that interferes with the child's activities of daily living and academic achievement. In order for a child to be diagnosed with DCD, these motor impairments must negatively affect some other aspect of his or her life. Impairment alone does not qualify a child for the diagnosis of DCD; the motor impairment must not be caused by or have the symptoms of an identifiable neurological problem" [9].

EMG: "Continuous recording of the electrical activity of a muscle by means of electrodes inserted into (or attached to) the muscle. The tracing is displayed on an oscilloscope. The technique is used for diagnosing various nerve and muscle disorders and assessing progress in recovery from some forms of paralysis" [10].

University of Cape Town

EQ-5D-Y: The Euroqol-5 Dimension-Youth (EQ-5D-Y) is a standardised and validated measure of health related quality of life in children. It provides a 5 dimensional profile with questions related to the following health domains: mobility, self-care, usual activities, pain or discomfort and anxiety or depression. It also includes a visual analogue scale that is used to describe the patient's perception of their health on the day of assessment [11].

fMRI: Functional magnetic resonance imaging refers to magnetic resonance imaging techniques that measure aspects of local brain physiology. The MR signal can be made sensitive to changes in blood oxygenation levels. Blood oxygenation increases in activated parts of the brain and these may be mapped using fMRI [12].

FRT: The Functional Reach Test is a standardised test that is used to assess balance and postural stability at the level of impairment. The FRT was developed for use in elderly patients but has been used in other population groups. During the FRT the subject is asked to reach out as far as possible beyond arm's length while maintaining a fixed base of support in standing. The distance reached is then measured [3].

GMFCS: The Gross Motor Function Classification Scale is an ordinal, standardised system used to classify children with cerebral palsy according to their motor function. This classification scale consists of 5 levels – Level I indicating few activity and mobility limitations and Level V indicating severe activity and mobility limitations [13].

GMFM: The Gross Motor Function Measure (GMFM) is a standardised and validated outcome measure that was developed to assess changes in gross motor function in children with cerebral palsy. Items tested include activities in lying, rolling, walking, running and jumping [14].

University of Cape Town

HR-QoL: Health Related Quality of Life refers to a multidimensional construct of quality of life that may include physical health, psychological state, social relationships, income, freedom and quality of environment [15]. Questionnaires that aim to assess Health Related Quality of Life include these domains as they may adversely affect health [16].

ICF: "The International Classification of Functioning, Disability and Health is a classification of health and health-related domains. These domains are classified from body, individual and societal perspectives by means of two lists: a list of body functions and structure, and a list of domains of activity and participation. Since an individual's functioning and disability occurs in context, the ICF also includes a list of environmental factors" [17].

KP: "Knowledge of Performance is a form of augmented feedback that provides the patient with information about the movement patters used to achieve the outcome of the movement trial or the kinematics of the movement" [18].

KR: "Knowledge of Results is a form of augmented feedback that provides the patient with information about the movement outcome relative to the task goal" [18].

MAS: The Modified Ashworth Scale (MAS) is a clinical assessment tool that is used to quantify spasticity, muscle tone or resistance to passive stretch. This is done by moving the patient's joint through range at a standard speed. The resistance to stretch is then rated on a 6 point scale (0, 1, 1+, 2, 3, 4) in increasing order of severity of spasticity [19].

NAP: When applied to Single Case Research, Non-overlap of all Pairs can be defined as "the probability that a score drawn at random from a treatment phase will exceed (overlap) that of a score drawn at random from a baseline phase" also referred to as "the percent of non-overlapping data between baseline and treatment phase" [1].

University of Cape Town

NDT: "Neurodevelopmental treatment was initially a treatment approach developed by Berta and Karl Bobath for the treatment of children with cerebral palsy. The philosophy of the treatment approach was based on a hierarchical view of nervous system function. The treatment for children with cerebral pasly focused on moving them through normal movement patterns to experience normal movement. Major components of this approach included reflex-inhibiting postures, inhibition of abnormal reflexes, normalization of muscle tone and adherence to the normal developmental sequence of motor progression" [20]. Over the past few decades, the approach has evolved as it became clear that too much emphasis had been placed on facilitation and adherence to normal movement patterns and it was appreciated that it was necessary for the child to take over control of his own movement [21]. In recent years, this approach has become more functional and goal orientated [20-22].

PAND: "Percentage of All Non-overlapping Data is the percent of all data remaining after removing the minimum number of datapoints which would eliminate all data overlap between phases A and B" in a single subject research design [1].

P-CTSIB: the Pediatric-CTSIB was derived from the Clinical Test of Sensory Interaction for Balance [3]. The P-CTSIB is used to assess the contributions of sensory information to standing balance in children [3]. Postural sway is investigated under 6 different sensory conditions: 1) eyes open, standing on a hard, flat surface 2) eyes closed, standing on a hard, flat surface 3) eyes open, standing on a medium density foam 4) eyes closed, standing on a medium density foam 5) eyes open, standing on a hard, flat surface with a visual conflict dome over the head 6) eyes open, standing on a medium density foam with a visual conflict dome over the head [3].

PDMS: "The Peabody Developmental Motor Scale is designed to assess the motor skills of children from birth through five years of age. The test is composed of six subtests that

University of Cape Town

include gross motor and fine motor skills. Composite scores are calculated from the results of the subtests" [23].

PEDI: The Paediatric Evaluation of Disability Inventory was developed as an outcome measure for children with disabilities. It consists of 3 parts namely 1) Functional skills (197 items) 2) Caregiver Assistance (20 items) and 3) Modifications (20 items). Capability is assessed in terms of functional skills that the child can achieve. Level of performance is measured in the amount of caregiver assistance needed in the Caregiver Assistance section. Each of the 3 parts of the PEDI is further subdivided into the categories of Self-care, Mobility and Social Function [24].

PET: "Positron emission tomography is a technique in nuclear medicine for cross-sectional imaging that enables a non-invasive assessment of localisation of metabolic activity to be made" [10].

PND: The Percent of Nonoverlapping Data is "the percent of phase B datapoints which exceed the single highest phase A datapoint" in a single subject research design [1].

RCT: "The randomised controlled trial is a comparison of the outcome between two or more groups of patients that are deliberately subjected to different regimes to test a hypothesis. Wherever possible those entering the trial should be allocated to their respective groups by means of random numbers and one such group (controls) should have no active treatment. Ideally neither the patient nor the person assessing the outcome should be aware of which group each patient is allocated to" [10].

ROC: For diagnostic work and test development in medicine, "the receiver operating characteristic curve is defined as a plot of test sensitivity as the y coordinate versus its 1-specificity or false positive rate as the x coordinate" [25].

University of Cape Town

ROM: "Range of Motion is motion available at any single joint and is influenced by associated bony structure and physiologic characteristics of the connective tissue that limits joint ROM" [26].

SEM: Where the standard deviation of a sampling distribution mean is estimated, it is called the standard error of the mean [27].

SES: Socioeconomic status refers to "an individual's or group's position within a hierarchical social structure" [28]."Socioeconomic status is defined by material wealth, occupation and participation in educational and social institutions. SES determines the substance of material life, from the foods and arts people enjoy, to the schools people attend and the social clubs and activities they engage in, to the likelihood of health- and mood-related vulnerabilities" [29].

SLST: "The single leg standing test is a measurement of sensorimotor control of the lower limb where the patient is required to maintain balance while standing on one leg. The test is usually timed and qualitatively assessed" [30].

SSRD: Single-subject research designs may be used to test the effectiveness of treatment in a single subject or a small group of subjects [31]. This design is characterised by repeated measures of a clinically relevant and observable target behavior over a baseline and an intervention phase [31]. Repeated measures allow subjects to act as their own controls [31]. A stable baseline is established with a minimum of three repeated measurements before treatment is introduced [32]. Data may be plotted and examined for differences in trend, level and variability of the baseline and intervention phases. A trend behavior of several data points allows the researcher to make inferences about the effectiveness of treatment and decreases the probability that improvement in the target behavior is owing to chance [31].

University of Cape Town

TBI: Traumatic Brain Injury is "an insult to the brain, not of the degenerative or congenital nature, but caused by an external force, that may produce a diminished or altered state of consciousness" [33].

TD: The term "typically developing" refers to the development of children who follow normal developmental milestones in the appropriate and commonly accepted time frame [34].

TS: "The Tardieu Scale is used to clinically assess spasticity by passive movement of the joints at three specified velocities. The intensity, duration and muscle reaction to stretch is rated on a 5-point scale, with the joint-angle at which this muscle reaction is first felt" [35].

TUDS: "The Timed Up and Down Stairs test was developed as a functional mobility outcome measure that would potentially reflect improvements in the musculoskeletal neuromuscular systems that contribute to the control of posture. The TUDS involves the subject ascending one flight of stairs, turning around, and descending to the starting point". Time to completion is recorded in seconds [36].

TUG: "The Timed Up & Go test was developed to assess basic or functional ambulatory mobility, or dynamic balance in adults. The standard TUG test for frail elderly people requires them to rise from a seat with armrests, stand momentarily, walk 3m, turn, return to the same seat and sit down. The score is the time in seconds from the instruction "go" to the person regaining their seat" [37].

TV: "The television is an electronic apparatus that receives such signals, reproducing images on screen and typically reproducing accompanying sound signals on speakers" [38].

University of Cape Town

VAS: "A Visual Analogue Scale is a measurement instrument that measures a characteristic or attitude that is believed to range across a continuum of values and cannot easily be directly measured".... "Operationally a VAS is usually a horizontal line, anchored by word descriptors at each end. The patient marks on the line the point that they feel represents their perception of their current state. The VAS score is determined by measuring in millimetres from the left hand end of the line to the point that the patient marks" [39].

VR: "Virtual Reality is the use of computer modelling and simulation that enables a person to interact with an artificial three-dimensional (3D) visual or other sensory environment" [40].

WHO: "The World Health Organization is the directing and coordinating authority for health within the United Nations system. It is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to countries and monitoring and assessing health trends" [41].

University of Cape Town

1. Introduction

1.1 Background

Cerebral palsy (CP) is a leading cause of childhood disability [42], occurring in 2 - 2.5 per 1000 live births [42] and the most common condition treated by paediatric physiotherapists [43]. About 33% of children with cerebral palsy have the hemiplegic form of CP [44] which is characterised by a unilateral brain lesion that results in paresis and spasticity contra-lateral to the involved brain hemisphere [45]. Children with hemiplegia usually attain motor milestones later than typically developing children and motor patterns differ from those of typically developing peers due to physical constraints caused by spasticity or paresis [45]. Most hemiplegic children are classified at Level I and II on the Gross Motor Function Classification System meaning that they are able to ambulate without a walking aid [46]. However, their hemiplegic gait comes at a great physiological cost due to deficiencies in coordination and force production of muscles on the affected side of the body [46 47]. Muscle activation is less selective and more global therefore decreasing quality and efficiency of movement [45] which may predispose to long-term musculoskeletal injury [48]. Weight distribution is usually uneven with the unaffected side supporting most of the body weight in the upright position [45]. This asymmetrical pattern of weight bearing, as well as inherent spasticity may lead to muscle atrophy, growth retardation and weakness on the paretic side [49 50].

Balance and postural control in weight-bearing positions are an integral part of gross motor function in activities of daily living [51] such as ambulation (stair climbing), dressing (standing on one leg to put pants on), self-care and hygiene (getting into and out of the bath) and social activities such as playing soccer (standing on one leg and kicking a ball). Children with hemiplegia have poor directional specificity as well as problems with the temporal and spatial activation of the appropriate muscles in response to balance perturbations [51]. They have also been shown to develop direction-specific postural control at a slower pace than typically developing children [52]. Damage to the

University of Cape Town

corticospinal tract in children with hemiplegic cerebral palsy [53] results in limitations of skilled motor performance as speed and accuracy of goal directed movement are deficient on the affected side [53]. Apart from difficulties with muscle co-ordination, children with cerebral palsy have difficulties with the integration of sensory information [2]. Slower sensory integration and processing contribute to an increased reaction time [53].

Studies investigating the benefits of balance training in children with cerebral palsy have demonstrated that effective balance recovery translates into more effective gross motor function shown by improvements on the Gross Motor Function Measure [54]. It appears that postural control mechanisms are still modifiable for children with cerebral palsy even in upper-elementary to middle school ages and that these improvements are retained after treatment cessation [54]. Therefore physiotherapy treatment for children with cerebral palsy should involve balance training as a focus of intervention [51].

There are a number of approaches to the rehabilitation of children with cerebral palsy. Arguably the most popular and widespread approach is the Bobath method, also known as Neurodevelopmental Therapy (NDT) [21 22 55]. Historically, this treatment approach included much facilitation with hands-on guidance by the therapist [20]. Children were assisted through normal movement sequences or components thereof with the aim of establishing or unlocking new and more effective neural pathways for the successful execution of movement [20]. A large amount of treatment time was spent inhibiting abnormal reflexes and normalising muscle tone [20]. A repeated failure to present conclusive scientific evidence to support this type of therapy [20] lead to a paradigm shift away from guided therapy where the patient is moved passively through movement sequences that may seem pointless to him/her. In recent years, a more active, functional and goal orientated approach to movement practice has been advocated [20 22 56].

Findings in the field of neurophysiology have contributed to the increased emphasis on task or goal orientated movement in rehabilitation [57]. Plasticity of the brain allows for

University of Cape Town

cortical changes to occur in response to movement experiences during active participation [57]. Practice, active participation and goal orientated movement are recognised as essential components of effective motor learning [58]. Therefore, it is said that one of the fundamental laws of motor learning is active repetition [57 58]. Motivation to practice and participate is often largely dependent on the movement task. Purposeful movement is more likely to promote active participation because the motivation to repeat a task is linked to the incremental success of completing a task and seeing the outcome [56].

In 2008, Nintendo released a gaming console that requires physical interaction in virtual situations presented to the player on the TV screen. The Nintendo Wii Fit is a balance board that consists of four force plate sensors that measure the patient's centre of pressure and weight distribution. This information is then incorporated in balance games such as snowboarding, skiing or heading a soccer ball. These games provide challenges that result in visually induced balance perturbations. The player engages in virtual reality situations by shifting his weight from front to back and side to side to meet the challenges presented to him in the game. This gaming equipment is commercially available and lends itself to the treatment of patients who struggle with balance control and weight shifting. The Nintendo Wii Fit is a highly task orientated and motivating form of balance training because the challenges presented in the games motivate the patient to practice and participate actively to improve the gaming score [59].

Apart from being motivational and challenging, the Nintendo Wii Fit is an affordable and commercially available form of biofeedback. The player receives immediate feedback in real time and can adjust movement strategies according to the outcome onscreen. The field of virtual reality rehabilitation has produced numerous studies that present a strong argument for the use of this type of visual biofeedback [58 60-64]. Patients are given the opportunity to explore affordances in an environment that is safe and enjoyable, therefore often leading to movement excursion and efforts that are much greater than those seen when the patient is given a set of exercises to complete [59 60 64].

University of Cape Town

Wii Fit exercise sessions have already been incorporated into the rehabilitaton of adult hemiplegic stroke patients in rehabilitation clinics and hospitals in Germany, the UK, and the USA and there is a website dedicated to "Wii-habilitation" [65]. However, the use of virtual gaming is relatively new in children with CP.

The WHO International Classification of Functioning, Disability and Health (ICF) has developed a conceptual framework with which to describe the different aspects of the disability process [66]. This framework proposes that interventions should not only target improvement of body structure and function (impairments) but that this improved function should be translated into acvitities of daily living and meaningful participation in society [67]. Wii Fit gaming requires active weight shifting for gaming. A correlation between self-induced weight-shift and ambulatory function in children with cerebral palsy has been demonstrated [68]. Therefore, it is plausible that hemiplegic children might benefit from the use of such a system where voluntary, independent and active weight-shifting practice is informed by immediate feedback from the gaming system, thereby leading to a reduction in balance impairment and possibly improvement in motor function, as proposed by the ICF.

If improvements are seen in balance control or gross motor function after intervention with the Nintendo Wii Fit, then this system would meet the requirements of an effective rehabilitation tool to address impairments, activity limitations and possibly even participation restrictions in children with hemiplegic cerebral palsy.

1.2 Aim and Objectives

Based on the above arguments, the aims and objectives of this study are presented below.

University of Cape Town

1.2.1 Aim

To assess whether intervention with the Nintendo Wii Fit improves balance and reduces activity limitations related to gross motor function in 7-14 year old children with spastic hemiplegic cerebral palsy performing at a GMFCS Level of I or II (independently ambulating).

1.2.2 Specific Objectives

To determine whether in a sample 7-14 year old children with spastic hemiplegic cerebral palsy performing at GMFCS Level I or II, intervention based on the use of the Nintendo Wii Fit will:

- Reduce impairments by improving balance control, measured by an adapted version of Subtest 5: Balance, of the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2).
- Reduce activity limitations by improving gross motor function efficiency in standing, running, jumping and stair climbing, measured by an adapted version of Subtest 6: Running Speed and Agility, of the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2) and the Timed Up and Down Stairs test (TUDS).
- Result in an improvement in the self perceived health related quality of life of the participants as assessed by the EQ-5D-Y visual analogue scale (VAS).
- Result in a sustained improvement in the above parameters over an 8-10 week period after intervention.

University of Cape Town

1.3 Research question

Does a Nintendo Wii Fit intervention given regularly over three weeks improve the balance and gross motor function of 7-14 year old children with spastic hemiplegic cerebral palsy performing at GMFCS Level I or II?

1.4 Significance of the study

The lives of children with disabilities are often excessively centered around rehabilitation, training and treatment. Due to the nature of their work, rehabilitation professionals are obligated to focus on the child's disabilities when therapy should ideally optimise the child's abilities. Physiotherapists should create a stimulating environment that meets the needs of children with disabilities to play and explore their affordances as do typically developing children. If empirical arguments can be made for the use of the Nintendo Wii Fit as a rehabilitation tool, then this might add an engaging yet effective and contemporary form of play to rehabilitation. The incorporation of the Wii Fit into rehabilitation protocols may contribute to a shift in the focus from medically orientated practice to activities that any typically developing child might engage in for the sole purpose of having fun. It is of great importance that therapists keep finding new and innovative ways to make rehabilitation enjoyable and empowering while still attaining goals of treatment [68]. The incorporation of such novel forms of rehabilitation will only become widely accepted once scientific evidence for their use has been presented. With the proposed study, the researcher hopes to contribute to this end.

University of Cape Town

University of Cape Town

University of Cape Town

2. Literature Review

2.1 Introduction

The WHO International Classification of Functioning, Disability and Health (ICF) presents a conceptual framework that assists rehabilitation professionals to obtain a holistic and coherent view of the impact that disability has on a patient's life [69]. This classification system provides a profile of the patient's disability in terms of their impairments, activity limitations and participation restrictions [66]. It is useful to evaluate the effectiveness of new treatment techniques in the light of the ICF framework [70]. In doing so, rehabilitation research is obliged to produce clinically important results that make a difference to the life of the patient [71]. The ICF conceptual framework has been used as a unifying concept within this literature review.

University of Cape Town

The following literature review presents arguments for the feasibility of utilising the Nintendo Wii Fit as a rehabilitation tool to improve the balance and gross motor function of children with spastic hemiplegic cerebral palsy. The different aspects of cerebral palsy are described in terms of the ICF framework, but with particular emphasis on school-aged children with hemiplegia. The review starts with epidemiological data and the different manifestations of cerebral palsy. Thereafter activity limitations and participation restrictions are discussed, particularly as they relate to mobility functions. A review of motor learning and postural control is presented as these pertain to physiotherapy interventions for children with cerebral palsy. The use of the Nintendo Wii Fit as a rehabilitation tool is considered in the context of physiotherapy intervention. In the last section of this review, the relevant outcome measures, research designs and statistical methods related to this study are discussed.

Appropriate literature for this review was sought by entering key words and concepts into the following databases: PubMed, CINAHL, PEDro, ScienceDirect, Medline and

BioMed Central. Some of the key words included were: balance, cerebral palsy, hemiplegia, virtual reality, centre of gravity, weight shift, hemiplegic gait, postural stability, motor learning, brain plasticity, bimanual activity, biofeedback, ICF, Gross Motor Function Measure, Pediatric Evaluation of Disability Inventory, Timed Up and Down Stairs, EQ-5D, health-related quality of life, Modified Ashworth Scale, goniometry, practice schedules and active participation. In addition to this, references of useful articles were investigated for further leads to other articles that were then accessed via the abovementioned data bases. Articles were limited to those published in English.

University of Cape Town

2.2 The epidemiology of cerebral palsy and congenital hemiplegia

The following section on the Epidemiology of Cerebral palsy is divided into the following sub-headings: Incidence and Prevalence, Classification, Diagnosis and Aetiology. There are several different types of cerebral palsy and each section progresses from a broader discussion around cerebral palsy as an umbrella term to a focus on congenital hemiplegia, since this is the target group under investigation.

2.2.1 Incidence and Prevalence

Over the past few decades an effort has been made to describe cerebral palsy in a holistic manner and not solely in terms of the child's motor impairment. One of the more recent definitions proposed in 2004 states: "Cerebral Palsy describes a group of developmental disorders of movement and posture, causing activity restrictions and disability that are attributed to disturbances occurring in the foetal or infant brain. The motor impairment may be accompanied by a seizure disorder and by impairment of sensation, cognition, communication, and/ or behavior" pg 222 [7]. Other definitions of cerebral palsy include that it is a neurological disorder caused by a non-progressive lesion of the brain [72].

The prevalence of CP is said to be roughly 2.0 per 1000 live births [42] although prevalence reports range from 1.5-3.0 per 1000 live births [73 74]. There is a strong association between gestational age and the incidence of cerebral palsy [75]. Due to an improvement in neonatal care over the past few decades, vulnerable pre-term infants have a greater chance of survival [76]. As a result, very low birth weight and pre-term infants constitute a large percentage of cerebral palsy cases [77]. In Europe, infants with a birth weight below 2500 grams now contribute to 50% of all cases of cerebral palsy and a little over 50% of the most severe cases [74]. In developed countries, hemiplegic cerebral palsy is said to occur in 0.79 per 1000 live births [78]. Hemiplegia constitutes roughly 33% of all CP cases [44 73]. While the number of diplegic children appears to be decreasing, the number of hemiplegic children is on the rise in developed countries [74].

In South Africa, limited information is available on the epidemiology of cerebral palsy. A retrospective investigation of hospital records undertaken at Tygerberg hospital in Cape Town showed that among the 242 records of children with cerebral palsy in 2003-2004, spastic quadriplegia was the most common type of CP (40.1%) followed by spastic hemiplegia (26.4%) and then spastic diplegia (14.5%) [79]. The predominance of spastic quadriplegia is thought to be due to a high rate of birth asphyxia, kernicterus and central nervous system infections commonly seen in developing countries [79]. These figures however are from one hospital record alone and may not be representative of South African national figures. To the author's knowledge, no studies reporting national figures of the incidence and prevalence of hemiplegic cerebral palsy have been published to date.

University of Cape Town

2.2.2 Classification

Cerebral palsy is the result of neuronal loss or damage due to brain trauma. The type of movement disorder is linked to the area of brain insult [80]. The American Academy for CP classifies the disorder into two categories: spastic pyramidal and extrapyramidal [80]. It is known that corticospinal (pyramidal) tract damage results in spasticity and hypertonia

[80]. Spasticity is defined as "a motor disorder characterised by a velocity-dependent increase in tonic stretch reflexes with exaggerated tendon jerk, resulting in hyperexcitability of the stretch reflex" pg 108 [81]. Spasticity may result in decreased dexterity, limitations in joint range, impaired mobility and increased energy expenditure [82 83]. Other corticospinal tract signs may include: weakness mainly in the antagonist muscles, poor movement precision, a Babinski sign and clonus [80]. Extrapyramidal damage may be in the basal ganglia or in the cerebellum [80]. Damage to the basal ganglia leads to dyskinesia [75 84] which refers to syndromes with involuntary movements (dystonia, athetosis, choreiform and tremor) [82]. Cerebellar damage leads to hypotonia and ataxia which result in an inability to grade force and accuracy of movement due to poorly coordinated muscle control [84]. More diffuse injury to the brain may result in mixed movement disorders with varying degrees of severity [80].

Classification of the different types of cerebral palsy may also be topographic. Topographic classification is more useful in spastic pyramidal CP than in CP of extrapyramidal origin since extrapyramidal cases usually present with involvement of all four limbs [80]. Spastic hemiplegia refers to a unilateral involvement of the body. Children with spastic hemiplegia are generally found to have corticospinal (pyramidal) tract damage in addition to somatosensory and motor cortex damage and as a result present with the pyramidal tract signs mentioned above [82].

Hemiplegia can be further classified into three categories according to Ingram's Classification [78]: Grade I is characterised by a mild hemiplegia with a unilateral increase in muscle tone and reflexes that result in discrete differences between the paretic and non-paretic side. Grade II is characterised by a moderate hemiplegia that clearly distinguishes the paretic from the non-paretic side due to muscle imbalances and resultant circumferential differences of the extremities, typical hemiplegic movement patterns and positive pyramidal tract signs [78]. Grade III is the densest form of hemiplegia with marked spasticity, obvious hemi-atrophy, pronounced pyramidal tract signs and an inability to use the upper limb in activities of daily living [78]. This type of classification

University of Cape Town

system is limited in that it describes children primarily in terms of their impairments and not in terms of their activity limitations.

The Gross Motor Function Classification Scale is used to classify children according to their functional abilities. Individuals can be classified according to 5 levels of ambulation that are prognostic of motor development [13]. General descriptors for each level are presented in the table below.

Table 1: GMFCS Level descriptors

GMFCS Level	Descriptor
Level I	Walks without limitations but speed, balance and coordination may be impaired.
Level II	Walks with limitations: cannot walk long distances and has trouble balancing on uneven terrain or when carrying objects and requires use of a handrail when climbing stairs.
Level III	Walks with a hand-held mobility device.
Level IV	Self-mobility with limitations. May use powered mobility.
Level V	Transported in a manual wheelchair.

85

University of Cape Town

Although other functional classification scales exist, the GMFCS is the most utilised method of functional classification as it has been studied extensively and has shown high inter-rater reliability [84]. Children with hemiplegia are generally found to fall into the Level I or Level II category of ambulation as most learn to walk but generally do not require hand-held mobility devices during ambulation [86].

2.2.3 Diagnosis

The early diagnosis of cerebral palsy may be based on a range of assessment techniques and indicators [87] which vary greatly in their predictive validity [87]. Consequently, making a definitive diagnosis of cerebral palsy is challenging in a young infant. Misdiagnosis is also not uncommon as neurological abnormalities presenting in the first few months of life may resolve over time, particularly in pre-term infants [84]. Conversely, CP may only be diagnosed once the child is older, as age-related neural requirements increase in complexity and it becomes apparent that motor milestones have not been attained [75]. A diagnosis of CP bears profound consequences for the individual and their family[88]. As a result, a multi-disciplinary approach and a combination of diagnostic methods should be implemented before making such a diagnosis [88].

Clinical observations and parental reports of developmental delay and motor deficits are arguably the most common and often the first diagnostic indicators especially of hemiplegic CP [75 84]. A failure to attain motor milestones and the persistence or delay in the disappearance of primitive reflexes is usually the initial indicator of a unilateral brain lesion [75 89]. A clear preference for the non-paretic hand to reach and grasp may be apparent from 3 months of age. In severe cases, independent sitting is delayed as attempts at sitting may result in falling to one side due to a lack of balance reactions [80]. Children with hemiplegic cerebral palsy tend to walk at 18-20 months post birth, an average of 6-8 months later than typically developing children [80].

A comprehensive neurological examination should be standard procedure after every birth. This serves to identify possible neurological abnormalities. Although the neurological exam is considered standard procedure, it may not always be successful in the early diagnosis of hemiplegic cerebral palsy [90] for the above-mentioned reasons. In a study by Bouza et al (1994), 5 children were diagnosed with unilateral brain lesions by means of Ultrasound and MRI [90]. These infants had either normal examinations or subtle abnormalities on physical examination at birth [90]. Abnormalities only became apparent at 6 months of age in these hemiplegic children and increased with time [90]. The onset of

University of Cape Town

hemiplegic signs was associated with the severity of the hemiplegia: the earlier the development of abnormalities, the more severe the hemiplegia [90].

2.2.4 Aetiology

Neurological damage may be of congenital or acquired origin. Brain lesions of children with congenital hemiplegia are usually considered to be of prenatal origin [91] although the aetiology of hemiplegic CP is unknown in roughly 25-30% of cases [80]. These include infants who were born at term or near-term with normal neonatal periods [84] and uncertainty regarding the aetiology may be due to the combination of risk factors contributing to the eventual brain lesion [84]. In general, the most common lesions are divided into 3 types: 1) periventricular lesions 2) cerebral malformations and 3) cortical or subcortical lesions [92]. In pre-term infants, the most common causes of hemiplegia are periventricular haemorrhagic infarction and periventricular leukomalacia [80]. In full-term infants the most common causes are cerebral malformations, cerebral or focal infarction and intracerebral haemorrhage [80]. An infarct in an area supplied by the middle cerebral artery is the cause of the lesion in more than 2/3 of hemiplegic children born at term [78].

Cerebral palsy may also be acquired peri-natally or post-natally. Causes of acquired CP may be traumatic, infectious, hypoxic or ischaemic in nature [75]. Only quadriplegic and dyskinetic types of cerebral palsy have been found to be associated with intrapartum hypoxic events. This association has not been found with hemiplegic, spastic diplegic and ataxic types of CP [93]. In the developing world, CP is more commonly acquired perinatally due to birth asphyxia and later in life due to infections of the nervous system (tuberculosis, bacterial meningitis, cerebral malaria) [79]. As a result, the incidence of quadriplegia is far higher in the developing world than in the developed world. This was reflected in the retrospective study by van Toorn et al (2007) undertaken at Tygerberg Hospital. It was found that the majority of CP cases (40.1%) were spastic quadriplegic. This was attributed to the high rate of severe birth asphyxia, and central nervous system infections [79]. In developed countries however, spastic diplegia is the most common type

University of Cape Town

of cerebral palsy and this can be attributed to the high survival rate of severely premature infants [79].

In addition to perinatal and postnatal events, socioeconomic status (SES) has been found to contribute to the risk of cerebral palsy [94]. A retrospective study in the UK found that some of the most important aetiologies of CP were mediated by SES [94]. Although no direct causal relationship could be reported, a strong association was found between SES and the risk of CP that was only partly accounted for by birth weight and gestational age [94]. Similarly, in Sweden, it was found that children from households with lower SES indicators had a higher Odds Ratio (1.49) of CP [95]. This decreased only marginally (1.36) after adjusting for perinatal indicators such as preterm birth, prompting the authors to report a socioeconomic gradient for CP in Sweden [95]. In their article, van Toorn et al (2007) reported that nearly all children with CP admitted to Tygerberg hospital in the Western Cape province of South Africa in 2003-2004 were from socially deprived backgrounds [79]. This may substantiate the findings made in Europe; however, it is possible that these figures are not fully representative of all children in the Western Cape as those from a higher SES might have been admitted to private hospitals. However, in their article on post-natally-acquired CP in Cape Town, Arens and Molteno (1989) suggested a causal relationship between SES and postnatally-acquired CP as the risk of postnatally-acquired CP is inversely related to the level of socioeconomic status: the lower the socioeconomic status, the greater the risk of postnatally-acquired CP [96].

University of Cape Town

2.3 Manifestations of cerebral palsy with particular emphasis on congenital hemiplegia

2.3.1 Impairments

The following section discusses common impairments seen in children with cerebral palsy but with particular emphasis on children with hemiplegia. Although impairments become evident at a very young age, this review discusses the impairments as they present in children at school age. A review of the motor development of children with spastic hemiplegic CP is beyond the scope of this study.

The ICF defines impairment as a significant deviation or loss in body function and structure [97]. Impairments related to cerebral palsy are central to its definition [98]. Cerebral palsy is primarily described as a disorder of posture and movement [98] and children with hemiplegic CP may suffer from a range of musculoskeletal, sensorimotor and cognitive impairments that may restrict or hamper functional movement. These are described below.

University of Cape Town

2.3.1.1 Musculoskeletal impairments

Abnormalities in muscle tone and function are common musculoskeletal impairments in cerebral palsy. Hemiplegic CP is characterised by paresis, spasticity or hypertonia contra-lateral to the involved brain hemisphere [45] and these may arguably be the most debilitating impairments. Paresis is characterised by "decreased voluntary motor unit recruitment" [81]. Paresis is said to accompany damage of the descending motor pathways. This disturbs the central excitatory drive to the motor units and leads to a deficient recruitment or modulation of motor neurons[81]. Voluntary force production is therefore reduced as a result of decreased motor unit recruitment [81].Wiley and Damiano tested the isometric lower limb muscle strength of 30 children with CP (15 spastic hemiplegic and 15 spastic diplegic) and compared it to that of 16 age-matched typically developing (TD) peers [81]. It was found that children with CP were not only weaker than their TD, age-

matched peers in all lower extremity muscle groups but it was also found that children with hemiplegia showed significant weakness on both the involved and uninvolved limbs [81]. Research now suggests that paresis is as detrimental to function as spasticity [81].

Hypertonia is an umbrella term that describes conditions of increased resistance to passive stretch, also known as increased muscle tone [99]. These conditions usually result in stiffness and shortening of the muscle and in more marked cases may lead to joint contractures with fixed shortening of soft tissue structures and decreased joint range [100]. Spasticity contributes to hypertonia [99]. It results from an abnormal stretch reflex, caused by changes in descending neural activity [81]. Changes in the stretch-reflex threshold are thought to be the underlying neural mechanism of spasticity [81]. Spasticity is defined as hypertonia "with one or both of the following signs 1) resistance to externally imposed movement increases with increasing speed of stretch and varies with the direction of joint movement, and/or 2) resistance to externally imposed movement rises rapidly above a threshold speed or joint angle" pg e91 [99] . As a result, it is commonly accepted that spasticity limits the child's ability to move quickly with dexterity, since spasticity is velocity dependent [81].

University of Cape Town

Spastic hypertonia and paresis together characterise a syndrome referred to as spastic paresis [101]. The clinical significance of the coupling of these impairments is that even when spasticity is alleviated by means of neurotoxins such as Botox, the underlying paresis remains [101]. This underlying paresis may perpetuate the cycle of hypertonicity. Hypertonia may be a primary impairment as is the case with spasticity or it may be a secondary musculoskeletal impairment. This is seen in instances where hypertonia is used in patterns of co-contraction to limit the degrees of freedom during movement in an attempt to increase stability at the joint [102].

Therefore, spastic hypertonia does not only describe hyperactive stretch reflexes but it is often also used to describe abnormal posturing [81]. In children with hemiplegia, a "spastic

pattern" may be seen in the affected upper and lower limb. The most common spastic pattern in the upper limb is shoulder internal rotation, elbow flexion, forearm pronation, wrist flexion, finger flexion with thumb-in-palm [103] [44]. In the lower limb the most common spastic pattern is hip flexion, hip adduction/internal rotation and knee flexion. An equinus deformity may be seen at the ankle if it is maintained in plantarflexion with weight bearing taking place mostly through the forefoot and toes [103]. As a result, the hemiplegic gait pattern may be devoid of heel-strike on the affected side [44] [104], although gait patterns may vary as described in section 2.3.2.

The equinus deformity, if present, may develop due to several reasons and morphological changes are not necessarily uniform in all children with spastic hemiplegia [105]. For instance, some children with an equinus deformity have tonic spasticity in the calf muscles while others have muscles that are stiff but are electrically silent on stretch [105]. Some children show hypertonia in relation to position while others have a shortened muscle with no hypertonia [105]. It has been shown that the tendency to decrease the loading of the hemiplegic leg during gait, causes morphological changes of the gastrocnemius muscle structure [106]. Muscle fascicle length and resting thickness is reduced in the paretic compared to the non-paretic limb [106]. Such changes in the muscle architecture of spastic muscles have negative implications for muscle function. The muscle resting thickness for instance, has been shown to be highly predictive of maximum torque and resultant muscle strength in children with CP [107].

University of Cape Town

Paresis, spasticity and decreased joint range, ultimately impact on the child's gross motor function. Consequently, as a result of paresis and spasticity, children with hemiplegia differ from typically developing children in their pattern of movement [45]. Children with hemiplegia usually attain motor milestones later than typically developing children [45]. Goh et al (2006) demonstrated a relationship between spasticity, muscle weakness and gross motor function [108]. It was found that children with more spasticity in the muscles surrounding the knee joint, were weaker on muscle testing, had lower Gross Motor Function Measure (GMFM) scores and less efficient gait [108].

Primary musculoskeletal impairments such as decreased muscle strength and increased tone translate into secondary impairments in balance and postural control which in turn influence gross motor function. Balance and postural stability impairments are largely due to deficiencies in muscle coordination and force production [81]. Postural stability is the capacity to control the body's Centre of Mass (COM) in relation to its base of support [109]. Centre of Pressure (COP) is the point where the resultant force vector of ground reaction forces from the supporting surface is applied to the body [8 110].While the COM is located in the vicinity of the trunk during upright stance, the COP is located in the sole of the foot [111]. Both COM and COP trajectories have been found to be good indicators of postural sway and balance control [8 111]. Studies looking at COP paths in postural sway have demonstrated that children with cerebral palsy have a significantly longer COP path as well as more directional changes in reaction to balance perturbations when compared to typically developing children [112]. This increased postural sway is largely due to deficiencies in the temporal and spatial aspects of muscle co-ordination and force production as well as difficulties with sensory integration [2]. Problems with sensory integration and processing contribute to delayed muscle activation because they result in prolonged reaction time [53].

The increased postural sway may also be due to poor biomechanics. Postural control is not only dependent on muscle recruitment but also on body alignment [81]. The alignment of body segments has a great influence on the effort required to maintain the COM over the base of support [81]. Alignment influences the movement strategies that are available to the subject. Children with hemiplegic cerebral palsy often have reduced joint range at the hip, knee or ankle in addition to deficient muscle recruitment [81]. The asymmetric alignment, where weight bearing takes place largely through the unaffected leg, may be seen as a strategy to compensate for muscle paresis in the hemiplegic leg [81]. This strategy, although functional, may not be ideal for reasons related to increased energy expenditure and long-term overuse injury [47 113 114]. When TD children were asked to perform a reaching task from a crouched position, it was found that their postural reactions resembled those of age-matched peers with CP [115], showing greater anticipatory postural adjustment variability and use of co-contraction activity. This

University of Cape Town

alteration in postural strategies in response to body alignment underlines the fact that altered biomechanical resting postures may add to deficiencies in postural control mechanisms [115].

In addition to the temporal and spatial problems in muscle co-ordination, children with cerebral palsy also differ from typically developing children in their distribution of muscle activation when responding to balance perturbations [51]. Analyses of balance strategies have shown that TD children display distal to proximal muscle activation thereby reacting to balance perturbations from the base of support up [51]. Children with cerebral palsy however, demonstrate co-contraction of the distal and proximal muscles as well as top-down muscle recruitment [51 52]. A study by Nashner et al compared the stance-balance reactions of children with spastic diplegic and hemiplegic CP with those of typically developing children[81]. Seven to ten year old children stood on a moving platform and were subjected to anteroposterior perturbations[81]. Children with spastic hemiplegia demonstrated the following in response to a backward platform perturbation producing forward sway: in the unaffected leg, a contraction of the gastrocnemius was seen first, followed by a contraction of the hamstring [81]. This resembles the muscle recruitment seen in typically developing children. The hemiplegic leg however showed a different pattern of muscle activation in response to perturbation and recruitment of the gastrocnemius was preceded by recruitment of the hamstrings [81]. This abnormal sequencing in the hemiplegic leg resulted in smaller torque generation in the hemiplegic leg compared to the unaffected leg [81]. It also resulted in a greater lateral shift of the COM than seen in TD children [81] making the balance strategy less efficient. The primary musculoskeletal impairments thus lead to secondary impairments in postural stability and this ultimately influences gross motor function.

University of Cape Town

2.3.1.2 Sensorimotor and Cognitive impairments

In addition to abnormalities in muscle tone and muscle activation, children with hemiplegic cerebral palsy often suffer from perceptual, sensory and cognitive

impairments that may become apparent through deficiencies in motor planning [98 116]. Delays in the transmission of information are inherent even in the normal sensorimotor system [116]. As a result, motor planning is necessary for effective and efficient movement [98 116]. "Motor planning is the ability to predict the future state of the motor system or the consequences of its actions" pg 15 [116] . Posture-based motor planning relies on the ability to predict movement outcome [98 116]. Only if the sensory consequences of a movement action are anticipated in advance, can effective posture-based movement planning take place [116]. Damage to the cortical and sub-cortical structures of the brain may lead to deficiencies in executive functions which include processes such as the "the ability to control impulses, anticipate consequences, establish goals,... plan and monitor outcomes and use feedback" pg e42 [117].

Studies show that anticipatory motor planning is compromised in young adolescents with congenital hemiplegia [98 116]. In addition to delayed muscle activation, the cognitive processes in planning appear to be affected [98 116]. Studies with hemiplegic children have shown that motor planning is not only deficient in the hemiplegic hand. Tasks completed with the unaffected hand also demonstrated poor motor planning suggesting a global deficit in motor planning [116]. Planning problems seem to be more prevalent in individuals with a left brain lesion than those with a right brain lesion [98 116]. This lack of motor planning may impact on the child's life as demonstrated in a study that showed impaired road crossing behavior in children with hemiplegic CP [98 116].

Anticipatory force planning is another aspect of motor planning. Deficiencies in anticipatory force planning have also been identified in individuals with congenital hemiplegia [98 116]. Poor force grading is not only related to impaired process skill abilities but also due to sensorimotor impairments commonly associated with hemiplegia. Koman et al (2004) reported the prevalence of these impairments (on the hemiparetic side) as follows: abnormal stereognosis (97%), diminished two-point discrimination (90%) and diminished proprioception (46%) [103]. Studies that compared force-production showed that hemiplegic children had an inability to gauge the force needed to grip an object as

University of Cape Town

well as the force needed to lift the object in relation to its weight, when using the hemiparetic hand [116] [118]. In contrast to the motor planning deficits, force planning deficits have only been found when movements were performed with the affected side [116]. Moreover when movements were performed with the unaffected side, the information gained from this action could be used in further trials to improve the force planning of the affected side [116]. Lifting the object a few times with the uninvolved hand subsequently resulted in improved force-production in the involved hand [116] [118]. This suggests that impairments in force production and motor planning may be improved with sufficient movement practice in conjunction with the unaffected side [116] [118].

2.3.1.3 Other Impairments

Hemiplegia may be accompanied by a number of other impairments that affect numerous body systems, in addition to those discussed above. Approximately 42% of hemiplegic cases suffer from at least one of the following: intellectual impairment, epilepsy, impaired vision, poor hearing and speech as well as behavioral and perceptual problems in varying degrees of severity [91]. Epilepsy is the most common complication of congenital hemiplegia with a prevalence of 27-47%. The level of intellectual impairment and the incidence of epilepsy are both strongly related to the severity of the hemiparesis [80]. Although binocular visual acuity was found to be below normal in 70% of a large cohort of children with CP, children with hemiplegic CP were the least affected. Abnormal acuity was found more often in children with tetraplegia and dyskinesis followed by diplegia [80]. Disturbances in eye motility and optic atrophy have been reported [80]. However, the ophthalmologic exam is often neglected and visual defects go untreated in a high proportion of children with CP [80].

University of Cape Town

2.3.1.4 Summary of Impairments

Children with hemiplegia suffer from a range of impairments that may negatively impact their postural stability and ultimately their gross motor function. These impairments include impairments of body structure namely paresis, spasticity, poor biomechanical

alignment and decreased joint range as well as spastic patterns of movement. Primary impairments may result in secondary impairments of timing and sequencing of muscle contraction. Impairments may also be of a sensorimotor nature such as deficient motor planning and process skill ability. Other problems such as reduced visual acuity, poor stereognosis and proprioception may further impede movement. This array of impairments may lead to activity limitations that prevent the child from functioning at a level appropriate for his/her age.

2.3.2 Mobility and Activity limitations

Impaired upper limb movement is considered the main impediment to independent function during activities of daily living in children with hemiplegic cerebral palsy [119] [120]. Spasticity and paresis as well as decreased range of motion (ROM) may considerably increase the effort required to perform upper limb activities that require gross and fine motor skills [119] [120]. Although reduced upper limb function may be the most debilitating factor contributing to reduced activities of daily living in children with hemiplegic CP, reduced lower limb function also plays an important role as it leads to limitations in mobility.

University of Cape Town

The Gross Motor Function Measure (GMFM) is an outcome measure designed to evaluate changes in gross motor function in children with cerebral palsy [14]. On the Gross Motor Function Measure (GMFM) children with hemiplegic CP often demonstrate a ceiling effect in their motor score since the GMFM measures the child's ability to perform movements such as crawling, sitting, running and jumping [121]. Although the GMFM shows children with hemiplegia to be higher functioning than children with diplegia and quadriplegia [86], their quality and ease of movement is not equivalent to that of typically developing children [119].

Van Zelst et al (2006) investigated how the impairments of children with hemiplegia impact on their activities of daily living [119]. Older children (9-12 years) were found to

have greater deficits in motor skill ability than younger children (3-8 years) suggesting that the gap between children with hemiplegia and typically developing children widens with age in terms of their motor abilities [119]. The mean motor skill ability for the older children was found to be at least two standard deviations below values reported for age-related peers [119]. Items that hemiplegic children generally find difficult include activities that require single-leg standing and eccentric unilateral control e.g. putting on a pair of pants or climbing over an obstacle, as well as activities such as stair climbing. These children usually struggle with activities that require fast propulsion of the affected lower limb e.g. jumping on the paretic limb and running. Indeed, Beckung and Hagberg (2002) found that in a sample of 176 Swedish children with CP (66 children with hemiplegia), 99% had some mobility limitations indicating that, although most hemiplegic children are ambulant, their altered gait pattern has an impact on their life [122].

It has been shown that the level of gross motor limitation is highly predictive of mobility, self-care and social function [121]. The Gross Motor Function Classification System (GMFCS) is a valid and reliable measure of activity limitations in children with cerebral palsy as it relates to their level of ambulation [13]. Children are classified according to one of five levels – the higher the level, the greater the limitations in motor function [123] (see Table 1 under Section 2.2.2). In terms of their impairments, children at level I and II of the GMFCS usually have a lower level of spasticity, fewer deviations in ROM and better motor control of the dorsiflexors than children at levels III and IV [97]. However, even in these children, hemiplegic gait comes at an increased physiological cost due to deficiencies in coordination and force production of muscles on the affected side [114 47]. Increased energy expenditure is a consequence of increased tone and gait abnormalities [124]. Energy expenditure during movement has been found to increase from the mildest form of CP (Level I) to the most severe form of CP (Level V) [124]. Although children with hemiplegia generally have the lowest increase in energy expenditure, their gait is still less efficient when compared to that of TD children [124].

University of Cape Town

According to Winter et al (1987), kinematically the gait of children with hemiplegic cerebral palsy can be categorised into 4 distinct patterns [125]. The first pattern is characterised by plantarflexion of the ankle during the swing phase ending in an equinus deformity at initial contact. To ensure toe clearance of the drop foot, hyperflexion occurs at the hip and knee. During the stance phase adequate dorsiflexion is available as there is no contracture in the Achilles tendon. The second gait pattern is characterised by a static or dynamic plantarflexion contracture resulting in continuous plantarflexion during both the stance and swing phases. The knee is hyperextended during mid stance and terminal stance. The third gait pattern is characterised by a stiff gait pattern as the quadriceps and hamstring groups co-contract and both remain active throughout the gait cycle. This limits knee flexion during the swing phase. Plantarflexion is maintained at the ankle throughout the gait cycle. The fourth pattern is identical to the third but is characterised by an additional reduction in sagittal plane motion. Increased activity of the Iliopsoas and the Adductors prevents full extension at the hip joint during terminal stance and there is a compensatory increase in anterior pelvic tilt. Riad et al (2007) reviewed Winter's classification system [126]. In a large-scale study of 112 spastic hemiplegic patients with a mean age of 8.5 years it was found that 23% of patients could not be classified under any of Winter's 4 gait patterns. As a result, Riad et al suggest that the classficiation system should be extended to include a group 0: a group that has the least deviations from normal gait and demonstrates dorsiflexion during the stance and swing phases [126]. This way, group 0, 1 and 2 would represent gait patterns that primarily involve deviations at the ankle joint. Group 3 would involve the ankle and knee and Group 4 would involve the ankle, knee and hip [126].

In terms of kinetics, hemiplegic gait is characterised by a large base of support as well as decreased step and stride lengths [113]. A decreased lateral weight shift to the affected side is seen during gait initiation [127] leading to the significantly shorter stance phase on the affected leg [8]. This leads to unequal load sharing as less time is spent on the affected leg during the gait cycle [127]. As time progresses this asymmetric muscle use may result in growth retardation or muscle atrophy of the affected side [49 50].

University of Cape Town

The reduced weight bearing capacity of the paretic limb is suggested to be the result of learned non-use. Learned non-use stems from difficulties in using the paretic limb and subsequent reliance on the uninvolved limb [113]. The child employs movement strategies that are biased towards the unaffected side as the primary movement solution and may severely neglect use of the involved limbs [113]. This reliance on the unaffected limbs may lead to poor weight shift to the paretic lower limb, deficiencies in balance reactions and an increased risk of falling [113]. As mentioned above, impairments such as muscle atrophy and reduced weight bearing on the paretic side may lead to further impairments such as leg length discrepancies that become more apparent as the child ages [113]. The primary impairment (spasticity, paresis and decreased proprioception) may therefore lead to activity limitations (an asymmetrical weight bearing pattern) which may lead to secondary impairments (leg length discrepancies) [113].

Independent function is important for active participation in society. Impairments and Activity limitations along with other factors may lead to limitations in participation. According to the ICF framework, these participation restrictions need to be addressed as a part of the treatment process.

University of Cape Town

2.3.3 Participation restrictions

Children with cerebral palsy are often at risk of reduced participation [128] and forced to live life on the sidelines of society as a result of their impairments and activity limitations. Participation is defined as "the involvement in life situations" and is strongly related to "what people do in real life" [129]. CP is associated with reduced participation in daily activities as well as a high prevalence of learning difficulties [117]. This may mean that children with CP have fewer educational and vocational opportunities later in life [117]. Participation in society is essential for the socialisation and self-esteem of all children [128].

Addressing participation restrictions according to the ICF framework is challenging when planning treatment. It has been shown that improvements in physical function do not necessarily translate into improved social participation [129]. Participation is heavily dependent on the geographical, structural, economic and social aspects of the patient's environment [129].

Virtual reality has been suggested to improve social participation by fostering independence and a sense of control and mastery during VR rehabilitation [68]. The incorporation of the Nintendo Wii Fit into a rehabilitation protocol might shift the focus from medically orientated practice to activities that any TD child might engage in thereby increasing participation in a world of technological advances. (Note that monitoring the impact of the use of the Nintendo Wii on participation was beyond the scope of this study).

University of Cape Town

2.4 Motor learning, postural control and physiotherapy treatment of children with hemiplegic cerebral palsy

Over the past few decades the fields of neuropsychology, brain imaging and EMG technology have caused a paradigm shift in the treatment of children with cerebral palsy. The following section includes a discussion on motor learning and postural control as these pertain to physiotherapy interventions that aim to improve postural control.

2.4.1 Motor learning: neural plasticity and brain reorganisation

Although CP is considered to be a non-progressive disorder of movement or posture, it should not be regarded as unchanging [130]. Although impairments impact on the acquisition of new skills, physiotherapy treatment is based on the belief that children with cerebral palsy are capable of learning new motor strategies. The field of

neuropsychology provides important guidelines and implications for physiotherapy treatment in terms of motor learning. Motor learning is defined as "the process of the acquisition and/or modification of movement" [81]. In the case of hemiplegic CP, for example, the child might learn to use the damaged motor system more effectively to achieve a movement goal that may have been achieved previously but in a less efficient manner [131]. The role of the therapist is to facilitate this process by identifying the underlying impairments but also the child's abilities. The therapist then creates an environment where new skills can be acquired and existing skills can be honed by drawing on the child's abilities [131 132].

Animal model research has shown that skill training may bring about changes in the brain as a result of neural plasticity [81]. Following brain injury, there are two mechanisms of neural plasticity that may contribute to recovery of function, namely restorative and compensatory [81] Restorative plasticity involves the resolution of injury and recovery of the injured tissue itself [81]. In compensatory plasticity, different neural circuits take over from damaged circuits and allow impaired function to be regained to an extent [81]. Brain plasticity and reorganisation have been studied extensively in congenital hemiplegia. These studies showed that paretic hand movements cause widespread bilateral activation of the motor cortex [133]. Conversely transcutaneous electrical stimulation over the intact motor cortex results in motor evoked potentials in the paretic hand [133]. This was in contrast to control subjects where hand representations in the primary motor cortex were strictly contra-lateral [133]. This substantiates the presence of motorneuron connections between the intact hemisphere and the ipsilateral paretic hand in patients with congenital hemiplegia. Similarly, experiments using PET scans in adult patients with capsular infarcts have also demonstrated that movement of the paretic hand showed increased blood flow in the damaged and undamaged hemispheres indicating that the undamaged hemisphere was contributing to the motor control of the hemiplegic hand [81]. This increased blood flow in both hemispheres was not seen in control subjects or when patients moved the non-paretic hand [81].

University of Cape Town

Primate studies have shown that the primary motor cortex and non-primary motor areas of the healthy brain are interconnected [133]. Parallel projections span via the corticospinal tract to the spinal cord [133]. A redundancy of connections is thought to underlie some of the reorganisation of the motor cortices that occur after brain injury [133]. Abnormally branched corticospinal tract fibres that originate in the intact hemisphere may to some extent be responsible for the control of the paretic upper limb [133]. These studies provide evidence that the task of controlling the paretic side of the body is redistributed across both hemispheres following an insult to one hemisphere of the brain.

However, the reorganisation of these motor pathways is said to be experience dependent [133]. Neurons compete for synaptic connections and these connections are use-dependent [81].When a dominant pathway is damaged, one of the many dormant pathways innervating the same sensory and motor cortex may initiate functional connections [81]. Studies investigating the effects of constraint-induced movement therapy (CIMT) have shown that, based on functional magnetic resonance imaging (fMRI) data, improved functional use of the hemiparetic arm is due to cortical re-organisation [113]. Although these CIMT studies investigated the use of the upper limb only, these findings may provide a sound scientific rationale for therapies that stimulate active use of the hemiparetic side of the body as this may result in cortical re-organisation and improved function [113].

University of Cape Town

Practice, active participation and goal orientated movement are recognised as essential components of effective motor learning [56 57 131]. Plasticity of the brain allows for cortical changes to occur in response to movement experiences during active participation [57]. Therefore, it is said that the fundamental law of motor learning is practice [57]. It has been found that for practice to be effective, it must be sufficiently challenging and effortful, if meaningful information processing is to occur in the brain [131]. Motivation to practice and participate is often largely dependent on the movement task. Purposeful movement is more likely to promote active participation because the motivation to repeat a task is linked to the incremental success of completing a task and seeing the outcome.

Therefore, task or goal orientated movement is increasingly emphasised in rehabilitation [57]. A study by Van der Weel et al (1996) investigated the performance of children with cerebral palsy on two different tasks [56]. The patterns of movement required for the completion of the tasks were essentially the same. One task involved concrete instructions of banging a drum while the other task required the child to hold the drumstick and rotate it actively as far as possible by pro- and supinating the wrist. The movement range was seen to increase in the hemiplegic hand to a greater extent when the drum banging task was performed. Supination range in the "abstract" task was 67% while in the drum banging task it increased to 93% of the full movement range. The authors go on to explain that movement is not only dependent on impairments and body function but also on the child's interest and the quality of information available about movement outcome [56]. Movement control tends to improve when the subject is required to interact with the environment in a cause and effect situation as opposed to performing movement for the movement's sake. Goal orientated or concrete tasks usually provide more informational support or feedback from the environment and are thus better suited for the acquisition of motor control [56]. This includes motor control strategies required for effective postural control.

Research is providing physiotherapists with important findings that should be considered when treating children with hemiplegic cerebral palsy. Studies in the field of neurology have shown that practice and use of both the affected and unaffected side of the body results in cortical reorganisation of the brain. This may be harnessed through interventions that challenge bilateral activity. The field of neuropsychology has provided evidence that active participation is fundamental to motor learning. Physiotherapy interventions that target postural control should therefore include activities that challenge postural control during functional, goal directed tasks as opposed to exercises that involve movement for the movement's sake alone.

University of Cape Town

2.4.2 Postural control: development and impact on movement

Skilled movement requires both postural stability and voluntary movement [81]. Postural responses provide a stable base for voluntary movement to take place[81]. Previously it was unclear whether postural movement and prime movement should be regarded as one and the same, however research has shown that separate neural control mechanisms exist for postural movement and prime movement [115]. Efficient postural movement is a critical aspect when coordinating movement of the different body segments [115]. Postural control involves the maintenance of static and dynamic equilibrium [115]. The sensory, motor and musculoskeletal systems have to integrate a large amount of information for postural control mechanisms to be effective [115]. Deficiencies in any of these systems may negatively impact their output [115].

The development of the sensory, motor and musculoskeletal systems is non-linear and takes place at different rates [115] and continues until the individual has attained adult-like patterns of postural control. Some controversy exists as to when typically developing children attain adult-like patterns of postural stability and balance. For many years results from a study by Shumway-Cook and Woollacott (1985) were seen as the standard time-line for the development of postural control. A group of 21 children ranging from 15 months to 10 years were assessed and it was found that children demonstrated adult-like postural patterns of balance control by the age of 7-10 years [134]. In recent years however, several studies with larger sample sizes and wider age ranges have shown that postural control matures much later in childhood and adolescence than was previously thought. Hirabayashi and Iwasaki (1995) found that postural stability in children only reached adult level by 15 years of age [135]. Similarly, a study by Peterson et al (2006) showed that typically developing children only developed adult-like sensory integration by the age of 12 years and therefore did not use adult-like patterns of postural control before the age of 12 years [136]. Children with cerebral palsy are known to reach motor milestones later than typically developing peers [80]. It may be that patterns of postural control development seen in TD children are similar in children with CP but somewhat

University of Cape Town

delayed. This leaves room for improvement and supports the use of postural control interventions for children with CP at school age.

Motor learning in children with cerebral palsy abides by the law that practice and task-related experience improve muscle coordination and efficient activation [137]. Studies have shown that balance control interventions in typically developing children accelerate the development of postural control [52]. It is possible that this would also be the case in children with CP. An intervention by Shumway-Cook et al (2003) showed that children with CP (seven to thirteen years of age) subjected to 100 balance perturbations from a force plate for five consecutive days showed significant improvements in time to stabilisation and mean area of center of pressure movement per second during balance recovery [54]. These improvements in reactive balance control were retained 30 days post intervention and improvements were also found on Dimension D (walking, running, jumping activities) of the Gross Motor function measure thereby proving that more effective balance recovery had translated into more effective gross motor function [54]. More importantly though, this study proves that postural control mechanisms are still modifiable for children with CP even in upper-elementary to middle school ages and that these changes seem to be preserved after treatment cessation [54]. If postural stability in typically developing children only matures in early adolescence, then balance control interventions at school age should be of benefit to such children. The same would be expected for children with CP as was demonstrated in the above-mentioned study by Shumway-Cook et al (2003).

Effective postural control requires the integration of a number of different action systems namely higher order planning as well as the generation and coordination of forces required to maintain postural stability [81]. During postural reactions, the nervous system recruits muscles in particular groups called synergies [81]. This functional coupling of muscles in response to postural perturbations reduces the degrees of freedom [81]. The task of maintaining postural stability by the nervous system is thereby simplified [81]. Along with these muscle synergies, subjects tend to use particular strategies in order to

University of Cape Town

balance. Anteroposterior balance perturbations require the patient to flex or extend the hip, knee and ankle in the sagittal plane. Mediolateral balance perturbations require a lateral shift of the pelvis along with adduction of the weight bearing leg and abduction of the non-weight bearing leg [81]. Although postural synergies are relatively uniform, they are flexible. Research has shown that postural synergies are task-specific and can be adapted [81].

Repeated exposure to a postural task strengthens neural connections involved in balance reactions between the sensory and motor pathways and therefore result in more effective postural reactions [81]. Forssberg and Hirschfeld (1994) describe two functional levels of postural control [138]. The first level refers to the gross direction-specific activation of correct muscle groups in response to balance threats thereby maintaining equilibrium. The second level refers to the ability to fine-tune this direction-specific muscle activity by integrating somatosensory, visual and vestibular information. Fine-tuning refers to optimising the timing, sequence and amplitude of postural muscle activity as well as agonist-antagonist co-ordination during direction specific adjustments [138] and this fine-tuning contributes to response efficiency. A study by Hadders-Algra et al (1999), investigated the postural adjustments in response to reaching in infants with cerebral palsy. It was found that their basic postural adjustment mechanism was intact however their capacity to modulate postural adjustments to task-specific constraints was not [139]. Similarly, the muscle activity of older children with CP was compared to that of TD aged-matched peers in response to three levels of perturbation difficulty [81]. While TD children were able to modulate the amplitude of the gastrocnemius muscle recruitment in relation to perturbation size, children with CP were not [81]. Instead children with CP had much lower contraction levels that remained relatively uniform regardless of the level of perturbation [81].

Postural control mechanisms require feedback and feedforward control. Feedback control refers to the use of postural adjustments made following an external perturbation that causes a loss of postural stability[81]. Feedforward control refers to the body's ability

University of Cape Town

to make postural adjustments in anticipation of potentially destabilising voluntary movement [81]. Although feedback control is very important to prevent falls and injury, feedforward control is probably the type of postural control used most often during movement. The automatism of feedforward control allows for the maintenance of balance during daily activities. This anticipatory postural control develops in response to previous experiences. It "pretunes" the sensory and motor systems to future balance perturbations [81]. In this way anticipatory control can support voluntary movement by providing a stable platform on which movement can take place. To a great extent, anticipatory postural control is dependent on practice and experience [115].

Deficiencies in anticipatory postural control were seen in children with spastic hemiplegic cerebral palsy when asked to push or pull a handle in standing [81]. EMG recordings showed a lack of preparatory muscle activity on the hemiparetic side. Preparatory activity was seen on the unaffected side of the body with postural and lower limb muscles being recruited before the onset of upper limb muscle recruitment. This preparation for movement was not seen on the hemiplegic side. Instead movement occurred before stabilisation as upper limb muscle activation preceded postural and lower limb activation [81].

Postural control is an integral part of gross motor function [109]. Poor balance control delays the acquisition of complex motor tasks such as walking [140]. Liao and Hwang (2003) investigated the relationship between balance and gross motor function by measuring postural stability in balance tests such as eyes open, eyes closed, single leg standing and heel-to-toe standing [141]. It was found that subjects with better postural control performed better on gross motor function tests [141]. A reduction in balance impairments and therefore an improvement in quality of movement, may thus improve overall gross motor performance.

University of Cape Town

Adequate trunk control is the basis for balance reactions and postural control [142] and the term trunk control is often used interchangeably with the term postural control. The role of the trunk has become increasingly emphasised in the last few decades. Core stability is advocated in most training and exercise regimes as a basis for safe and efficient movement. Trunk control affects limb tone, range of motion and motor control [143]. Poor trunk control leads to compensation by other muscles, usually the primary movers of the extremities [144]. This compensation reduces their effectiveness as primary movers [144]. This principle is supported by observations that children with CP have reduced ambulatory ability even when the proximal muscles are primarily affected and the distal limb musculature is less affected [144].

The role of the trunk during balance reactions has been investigated more extensively with advances in EMG technology. Decreased trunk muscle recruitment has been found in children with cerebral palsy during stance balance control [140]. Earlier hypothesis proposed that ankle inputs from stretched lower limb muscles triggered balance corrections in a distal to proximal manner in healthy subjects [145]. However, it has been found that stretch and unloading reflexes occurred earlier in the trunk than in the ankle muscles [145]. Secondly, trunk muscles have timing and amplitude characteristics necessary for directional information that are not seen in lower limb muscles [145]. As a result, it now appears that balance correcting responses are triggered first in the trunk and then in the lower limbs [145].

University of Cape Town

Deficiencies in trunk control are also linked to poor upper limb function. In healthy infants, it was found that postural control is crucial for the development of reaching behaviour [146 147]. The trunk musculature must offset the gravitational forces acting on the body during dynamic tasks [146]. As mentioned in the paragraph on feed-forward control, the individual must anticipate the reactive forces that will arise during movement [146]. The trunk provides support for upper limb activity to take place [147]. Trunk motion must be integrated to propel the arm during movement [147]. Children with hemiplegia have difficulties in modulating and dissociating arm and trunk movement for

task-specific activities [147]. Studies have shown that in TD children, arm-trunk inter-joint and inter-segment coordination continuously develops even into late childhood [148]. As a result, the goal of improving trunk control in school-aged children with hemiplegia may improve upper limb function. This would be desirable as impaired upper limb activity is generally regarded as the greatest impairment to activities of daily living in children with hemiplegic cerebral palsy.

In summary, trunk muscle activity and therefore postural control is impaired in children with cerebral palsy. Ultimately, the first level of postural control (direction specificity) is often intact in children with hemiplegic cerebral palsy, but the second level of postural control (fine tuning the amplitude of muscle contraction) is usually deficient to a certain extent [138]. Impaired postural control leads to mobility limitations and limitations in the activities of daily living. Contrary to what was previously thought, it appears that postural control is not yet fully developed in children at upper-elementary to middle school ages. It is therefore of interest to the physiotherapist to focus on trunk and postural control as a goal for treatment. The following section presents the rationale for postural control interventions for school-aged children with cerebral palsy.

University of Cape Town

2.4.3 Physiotherapy interventions to improve postural control

The research cited above shows that aspects of postural control may improve when children are repeatedly exposed to situations that challenge response efficiency. Although children with hemiplegic cerebral palsy suffer from a range of impairments that may be addressed by different treatment options, only those which are relevant to the intervention under investigation are included in this review. However a summary of treatment options can be found in Appendix No 8.1. What follows is a discussion on the role that physiotherapy has in the lives of CP children who suffer from deficiencies in postural control and how physiotherapy may harness the postural affordances that are available to children with hemiplegic cerebral palsy.

Arguably, the primary role of physiotherapy is to optimise the child's movement strategies in order to attain the highest possible level of independent function. When the child is an infant, this might involve stimulating the acquisition and progression of motor milestones. As the child grows older, a plateau is reached in terms of motor milestone acquisition [149]. Further acquisitions in motor skills are rare beyond this point [149]. This widely accepted principle was demonstrated by Rosenbaum et al (2002) in a large scale longitudinal study of Canadian children with cerebral palsy [149]. Motor growth curves showed that the child's GMFCS level was predictive of the point when the child was likely to plateau in terms of motor abilities [149]. These motor growth curves allow for a prognosis of the child's future motor function [149].

Even though children were found to reach a plateau on the motor growth curves, Rosenbaum and colleagues stress that these motor growth curves were based solely on the items of the GMFM-66 and that further treatment (or cessation thereof) beyond the predicted plateau point should not be based on a stagnating GMFM-66 score alone [14]. Instead it was noted that children may continue to experience improvements in movement quality which may, in turn, improve all gross motor performance [14]. Indeed, the motor growth curves show great variation between subjects within age groups and GMFCS levels [150]. Some children plateau earlier than others and some continue to improve past the predicted plateau point. It would therefore be incorrect and unethical to assume that all children plateau at a predicted age and that treatment should be ceased on the basis of motor growth curves alone [14]. The benefit of physiotherapy should be weighed up for each child individually [150] and it is the role of the physiotherapist to ensure that each child realises its full potential .

Apart from the between-subject variation in terms of plateau point on the motor growth curves, it appears that there is also a variation in responsiveness to treatment in children with cerebral palsy. Constraint induced movement therapy studies have shown that functional gains are not equal for all children with hemiplegic CP [6]. Children who have only a moderate level of impairment, benefit the most from constraint induced

University of Cape Town

movement therapy [6]. A possible reason may be that severe levels of impairment (spasticity, reduced ROM, reduced sensation and proprioception) create a barrier to learning new movement strategies [6].

According to Shumway-Cook and Woollacott (2006), interventions are often targeted at alleviating underlying impairments with the aim of enhancing the patient's strategies for postural control [81]. However, evidence suggests that treatments aimed solely at reducing impairments such as muscle weakness and decreased joint range, do not necessarily translate into improved balance control [81]. Therapeutic activities targeting specific aspects of balance control are more likely to be effective [81].

As discussed in 2.4.1, it has become increasingly apparent that functional gains from therapy are best retained and carried over if the patient is encouraged to participate in goal directed and task orientated activity. A functional approach to therapy is currently advocated with the emphasis being on the child's ability to perform the activity "as functionally as possible and not as normally as possible" [151]. Instead of guidance through handling and facilitation, an environment is created where the child explores self-initiated strategies under certain task constraints [151]. The interplay between postural control and movement is emphasised: movement experience improves postural control and improved postural control promotes efficient movement [152-154].

Physiotherapy approaches to improving balance and postural control range from basic physical tasks like throwing and catching a ball [155] to the utilisation of specialised, technical equipment such as Biofeedback [156 157]. Arguably one of the most commonly utilised forms of physiotherapy treatment for children with cerebral palsy is the Bobath method/Neurodevelopmental Therapy (NDT) [21 22 55] . The core philosophy of NDT is that Central Nervous System dysfunction interferes with the development of postural control which in turn restricts normal motor development [21]. The approach focuses on influencing the sensorimotor components of muscle tone, reflexes, postural control,

University of Cape Town

sensation and perception [21 22 158]. Previously, handling techniques were implemented to inhibit spasticity and abnormal movement patterns and to facilitate normal equilibrium reactions and muscle tone [21 22]. As a result, the patient was largely passive in his own treatment [21]. These treatment principles changed with the advances in the field of neuroscience. The importance of voluntary active and functional movement was increasingly recognised, particularly with regards to postural control and balance [21 158]. Currently, ND therapy emphasises the task specific preparation for function [21 158 159] with progressively less manual input and facilitation from the therapist. A review by the American Academy for Cerebral Palsy and Developmental Medicine reported no advantage of NDT to other alternative therapies [21]. Other research appears to be inconclusive. A review by Anttila et al (2008) summarised that NDT combined with an Adeli suit was found to improve mechanical efficiency in stair climbing [160]. Functional training was found to be more effective than NDT to improve walking, running and jumping on the GMFM while infant stimulation followed by NDT was found to result in better motor and developmental quotients and walking function than NDT alone [160]. The paucity of evidence supporting NDT is partly thought to be a result of inadequate research methods that may undermine the value of NDT. Butler et al (2001) suggest that studies of greater methodological quality may rectify the current weakness in evidence for the use of NDT [21].

University of Cape Town

Therapeutic riding, also known as hippotherapy, is an intervention thought to improve posture and balance and therefore motor function of children with cerebral palsy [161]. The multidimensional movement of the horse challenges the maintenance of postural stability [162]. This form of therapy is highly task orientated with the motivation for the patient being to stay seated and righted on the horse [162]. Although Hippotherapy is based on external perturbations opposed to self-induced balance perturbations, this type of therapy resembles the Wii Fit in terms of its functional nature. The child is immersed in a situation where the outcome of the task at hand is directly dependent on the child's ability to engage their balance reactions and postural control. Multiple studies have shown improvements in posture and gains on the Gross Motor Function Measure following Hippotherapy interventions [20 162-164]. Hippotherapy was found to improve

dynamic postural stabilisation and balance recovery as well as anticipatory and feedback postural control [165].

Interventions aimed at improving postural control should ideally challenge all 3 aspects of postural control namely: steady state, anticipatory and reactive postural control [81]. This would include activities where the COM is moved in relation to the base of support as well as activities where the base of support is moved requiring recovery of stability of the COM [81]. The Nintendo Wii Fit balance board makes the former requirements of the player during gaming. It challenges the player to anticipate the movements required for successful gaming and provides him with an element of surprise to draw on the players' reactive postural control. It is possible that the anticipatory and reactive postural mechanisms employed during gaming may be drawn on during gross motor activities such as climbing stairs, jumping and walking on a line. In the following section, arguments for the Nintendo Wii Fit as a rehabilitation tool are presented.

University of Cape Town

2.4.4 The Nintendo Wii Fit balance board as a rehabilitation tool

The Wii Fit is a commercially available gaming system designed by Nintendo. Motion sensor technology is used to engage the player in video gaming. The Wii Fit balance board is a five cm high board that is placed on the floor 1.5 m in front of the television screen. The player stands on the board and the four force plate sensors in the balance board measure the pressure input through contact with the person's feet.

Figure 1: Nintendo Wii Fit balance board

http://www.techgadgets.in/images/nintendo-wii-fit-us.jpg [166]

There has been a growing interest in the use of the Nintendo Wii Fit for rehabilitation purposes since its release in 2006. A number of hospitals and rehabilitation clinics in Germany, the UK and the USA have started incorporating the Wii Fit into the rehabilitation programs of hemiplegic stroke patients, patients with traumatic brain injuries and amputees. A website dedicated to "Wii-habilitation" [65] displays internet articles and news reports related to the use of the Wii Fit in rehab. These articles contain reports of the positive results experienced by therapists and patients alike. The use of the Nintendo Wii Fit as a rehabilitation tool is currently being investigated in children with Traumatic Brain Injury (TBI) by Ms Danielle Levac (personal communication) at McMaster University in Canada and in children with Developmental Coordination Disorder (DCD) by Mrs Dorothee Jelsma (personal communication) at the University of Groningen in the Netherlands and there may be others engaged in similar research.

Biofeedback is a method of rehabilitation that utilises electronic or electromechanical instruments to measure and feedback information about performance by means of visual

University of Cape Town

or auditory signals [104]. Biofeedback is a way to augment sensory input [167] and improve body awareness during movement [104]. A study by Seeger et al (1981) tested whether the gait symmetry of hemiplegic children could be improved by providing auditory feedback [168]. Four children between the ages of 7-11 years were asked to walk with load-sensitive insoles on the hemiparetic side [168]. Auditory feedback from the sensors encouraged children to increase weightbearing on the hemiparetic leg [168]. The gait cycle symmetry was significantly improved by this feedback and improvements were retained after treatment had ended [168].

The Nintendo Wii Fit Balance board may be seen as a form of Biofeedback that translates COP measurements and ground reaction forces into results on the television screen. Gaming performance is an objective measure of the patient's ability to shift weight in a multitude of directions. The advantage of the Nintendo Wii Fit is that it provides Biofeedback indirectly via a suprapostural task. The acquisition of postural control is said to be more efficient and lasting when attention is directed away from the body to an external focus [169]. Directing attention away from the body promotes the automatism that is necessary for postural control [169]. Children appear to benefit more from an external reference (following a visual model) than from an internal reference (focusing on their technique) when performing activities that involve multiple degrees of freedom [18 56]. It is hypothesised that the sensorimotor impairments of children with cerebral palsy make it particularly difficult for the child to improve movement strategies by focusing on their technique [18]. When playing Nintendo Wii Fit games, the user is not focusing on their own body reactions as such but rather on their performance in the game which then provides meaningful biofeedback for balance training.

Virtual reality rehabilitation refers to the stimulation of movement with the help of a virtual computer generated environment. The patient is either placed in front of a television or computer monitor or is made to wear head gear that allows images to be projected on a screen. The patient then interacts with the virtual environment by moving

University of Cape Town

in response to the challenges presented. Findings from virtual reality (VR) rehabilitation studies provide a strong argument for the use of gaming in rehabilitation.

Flynn et al (2007) investigated the feasibility of using the Sony PlayStation 2 (PS2) EyeToy for an individual in the chronic phase of post-stroke recovery. The PS2 EyeToy is a gaming system that resembles the Wii Fit in presenting the player with movement challenges using a television screen as the interface. Training involved 20 one-hour sessions over four and a half weeks. It was found that the patient improved on numerous standardised motor and balance outcome measures following the PS2 intervention. Flynn et al concluded that a low cost, commercially available gaming system such as the PS2 would be a useful adjunct to post stroke rehabilitation [170]. Similar results were demonstrated in a case report involving an adolescent with diplegic cerebral palsy. Deutsch et al (2008) investigated the effect of the Nintendo Wii Fit on a 13 year old male with diplegic cerebral palsy classified as level III on the GMFCS. Games that involved upper limb activities such as tennis, golf, boxing, bowling and baseball were played. The intervention consisted of 11 x 60-90 minute sessions over four weeks. Visual-perceptual processing, postural control and functional mobility all improved during and post intervention [171]. These case reports are specific to their participants and do not allow for inferences to be made to larger populations due to the single subject study design. However, the results from such studies are promising and serve as pilot studies for subsequent research on the use of commercially available gaming systems for rehabilitation.

University of Cape Town

Virtual environments similar to the one provided by the Nintendo Wii Fit have been used to improve symmetrical weight distribution. In a pilot study by Lott et al (2003) an individual with right hemiparesis was required to interact with a virtual snowboarding environment while standing on a force platform (much like the Wii Fit Balance board) [60]. Weight shifting and leaning were required to avoid trees and obstacles on the virtual ski slope. Weight bearing time spent on the non-paretic leg was decreased progressively from 73% to 55% effectively increasing the weight bearing time of the paretic leg by

18% [60]. The patient spent 45% of the time weight-bearing on the paretic limb within 12 minutes of intervention indicating a fairly rapid and substantial increase in weight bearing symmetry [60].

Anticipatory postural control is deficient in children with cerebral palsy as described in the section on the development of postural control. It has been suggested that active weight shifting activities are effective in improving anticipatory postural control [115]. Westcott and Burtner (2004) suggest that weight shifting should be incorporated into functional activities rather than practised in isolation [115]. Liao et al (2001) also found a close correlation between self-induced weight-shift ability and ambulatory function in children with cerebral palsy [4]. The Nintendo Wii Fit requires the player to actively shift weight during gaming. Weight shifting practice that is embedded in the task of gaming may improve anticipatory postural control, self-induced weight shifting abilities and ultimately ambulation and gross motor function.

Virtual reality studies have been proven to provide the patient with challenges to explore affordances in a safe environment [61]. For instance, in an experiment by Lott et al (2003), healthy subjects were asked to lean as far as possible to touch the hands of research assistants in a real world scenario and then to perform similar reaching tasks in a game-like context of goal-keeping in a virtual reality scenario. The virtual reality tasks resulted in much larger COP excursions than the real world scenario. The addition of a game-like task appears to have motivated subjects to reach much further in response to performance feedback from the television screen [60]. Allowing the subjects to focus their attention on the game instead of their balance may have prevented them from underestimating their true balance abilities as might have occurred in the real world scenario [60]. The equipment used in this study was specialized laboratory equipment that is not readily available to physiotherapists in a school setting. However the Nintendo Wii Fit is similar in the sense that the player is immersed in a virtual environment that presents movement challenges. Similar improvements in weight shift may therefore be

University of Cape Town

expected. The Nintendo Wii Fit is also commercially available and easy to operate and therefore lends itself to weight shift training in a public setting.

Virtual reality rehabilitation has also been shown to induce cortical reorganisation. In a study by You et al (2005), an 8 year old individual with a right hemiparesis underwent a virtual training program where he was required to move around in the real world while manipulating objects in the virtual world. These activities were designed to facilitate range of motion, mobility, strength, and reaching skills. The training program consisted of 60 minute sessions, five times a week for 4 weeks. Functional magnetic resonance imaging was used to map brain activity. Before the VR therapy, the bilateral primary sensorimotor cortices and ipsilateral supplementary motor areas were activated during movement of the hemiparetic limb. After VR therapy, the altered activations ceased and the contralateral sensorimotor cortex was activated during movement of the hemiparetic limb. Changes seen on fMRI were associated with enhanced functions such as reaching, self-feeding and dressing that were not possible before VR therapy [172].

The widespread enthusiasm in embracing the Wii Fit as a rehabilitation tool may be in part due to the successes that have been seen in clinical studies using Biofeedback and Virtual reality. The Wii Fit essentially combines both these treatment modalities in one system. The Nintendo Wii Fit requires self-induced weight-shifting abilities for the player to interact with the virtual environment. As a result, it may be expected that improving the self-induced weight shifting ability as well as anticipatory postural control of children with CP, may improve their quality of gross motor function. Similarly, when playing the Nintendo Wii Fit games, the advantage of virtual world goal-keeping opposed to real-world goal keeping is that it provides a sense of achievement without the potential threat of injury to the patient [59].

No controlled trials have been reported thus far, that support the claims that the Wii Fit improves balance in children with hemiplegic cerebral palsy. A pilot study by Nitz et al

University of Cape Town

(2009) reports that the feasibility of using the Wii Fit to improve balance, strength, flexibility and fitness was tested on a group of ten healthy women aged 30-60 years. Results showed that balance and lower limb muscle strength improved significantly but changes in proprioception, cardiovascular endurance, mobility and activity level were not significantly changed. The authors report a trend towards an immediate effect on balance and strength due to activity fostered by the Wii Fit which needs to be confirmed in studies with greater statistical power [173].

In addition to possible gains in balance and strength, it may also be postulated that the Biofeedback properties of the Nintendo Wii Fit Balance board can be used to aid in an improvement of motor planning and force planning of children with congenital hemiplegia. As mentioned in section 2.3.1, these functions have been shown to be deficient in this population. The Nintendo Wii Fit COP measurements that are translated into actions on screen require careful grading of weight shifting from one leg to the other. A weight shift of too great or too small a magnitude might result in the player falling off the sheet of ice, bursting his traveling bubble or not heading the soccer ball. Motor planning and force grading is required when playing the Nintendo Wii Fit games.

Although the Nintendo Wii Fit should not replace conventional therapy, it has considerable merit as a motivating adjunct to therapy [62]. The Nintendo Wii Fit is a highly task orientated form of balance training because the challenges presented in the games motivate the patient to practise and participate actively to improve the gaming score. The subject's heightened enthusiasm for VR gaming as a form of rehabilitation was confirmed in a randomised controlled trial with a group of traumatic brain injury subjects. Some underwent virtual reality balance rehabilitation while others were assigned to conventional Physiotherapy balance interventions [63]. Improvements in balance and functional mobility were seen in both groups. The VR group however showed greater improvements on quantitative measures and expressed greater interest and excitement in their therapy [63]. This is in agreement with trials done by Bryanton et al (2006) that showed how children had increased dorsiflexion range and longer holding

University of Cape Town

periods when interacting with a virtual reality game opposed to conventional exercise regimes. Parents as well as children reported greater interest and enjoyment in exercising with the game-like intervention compared to the conventional exercises [64].Reports such as these make the use of virtual reality gaming systems a promising rehabilitation tool with regards to participation and compliance.

Improvements following virtual reality rehabilitation are not strictly limited to the physical realm. It has been shown that the provision of objective and positive feedback in virtual reality rehab empowers subjects through a sense of control and mastery and improved self-esteem [68 174]. The participation restrictions that children with cerebral palsy deal with may be detrimental to their self-esteem [175]. Allowing children to take part in activities that their typically developing peers might enjoy may improve their self-concept and independence [175].

Although subject participation and skill has been shown to improve in VR rehabilitation, the question remains whether these skills can be transferred beyond VR environments. The philosophy underlying the ICF requires the medical community to prove that interventions not only improve body structure and function but that this improved function translates into activities of daily living and participation [67]. Rehabilitation is only effective if newly acquired skills can be transferred to real world situations [176]. A review of studies investigating the effect of virtual reality therapy for persons with disabilities concludes that these patients are able to learn in virtual environments and that motor learning is transferred from the virtual environment to the real world. Newly learnt skills can be task specific but carry-over to other tasks has also been shown after intervention with virtual reality training [62]. Therefore, theoretically speaking, improvements in balance control and postural stability after intervention with the Nintendo Wii Fit may be expressed in improved gross motor function and functional mobility. If this is the case, then improvements should be seen on the outcome measures chosen for this study.

University of Cape Town

To summarise, the Nintendo Wii Fit may be seen as a combination of Biofeedback and Virtual reality technologies. Studies investigating the benefits of these technologies have shown gains in symmetrical weight bearing, movement excursion, motor and force planning, motivation to practise and self-esteem. However previous studies were limited to case reports or larger sample numbers of healthy subjects. The use of the Wii Fit in children younger than 13 years of age has not been reported and although virtual reality studies have been undertaken in hemiplegic stroke patients, no investigations utilising this technology for children with hemiplegic cerebral palsy have been published to date. Nevertheless, it is reasonable to expect that the benefits reported in other population groups may also be seen in children with hemiplegic cerebral palsy following a Nintendo Wii Fit intervention. Treatment schedules and intensity of therapy need to be considered for such an intervention. The findings from rehabilitation studies regarding the ideal parameters of treatment are presented below.

University of Cape Town

2.4.5 Practice schedules: frequency and structure of therapy

The amount of motor learning during therapy is dependent on the practice schedule. The structure of the therapy session, as well as frequency of therapy contributes to the efficacy of treatment. The amount and type of feedback given as well as the periods of activity and rest have to be considered when structuring therapy.

Optimal intensity of therapy has been debated for a few decades. Previously, children were given fewer therapy sessions over a prolonged period of time. More recently, the benefits of blocked therapy were recognised. A number of studies have proven that shorter periods of intensive therapy are more beneficial than longer periods of less intensive therapy. Bower et al (1992) conducted a study during which children were assessed over a period of 9 weeks. During the first 3-week period, children received routine therapy for half an hour, once a week. In the second 3-week period, children received an hour of therapy 5 times a week. During the last 3 week period, children reverted back to their routine therapy for half an hour once a week. This study showed

that a three week period of intensive therapy accelerated the acquisition of motor skills. Once children had reverted back to their regular Physiotherapy routine, the mean assessment score dropped somewhat but remained higher than the mean assessment score in the baseline period indicating that some of the motor skills that were acquired during the intensive 3 week period had been retained [177].

Similar benefits of blocked therapy were shown in a study by Trahan and Malouin (2002) [178]. Subjects were randomised to a multiple baseline study design with an A,B1,C1,B2,C2 design. During the A phase, children underwent therapy twice a week for 45 minutes. This phase lasted up to 12 weeks for some subjects due to the staggered multiple baseline design. In the B1 phase therapy was increased to four times a week for 45 minutes. During the C1 phase, therapy was completely withdrawn and children were given a rest period of 8 weeks. The B2 phase was identical to the B1 phase in terms of treatment dosage and was followed by another C2 phase of complete rest for eight weeks. The rate and magnitude of improvement varied among subjects but all children showed an improvement in their motor performance scores that remained higher than the pre-experimental motor performance score throughout the study. Even during the C phases where treatment was withdrawn, the GMFM scores did not drop significantly thus suggesting that a four week program of four sessions per week was beneficial to motor learning.

University of Cape Town

A study by Gagliardi et al (2008) compared two types of treatment schedules [179]. A group of forty subjects was subdivided into 2 groups of 20. One group was given a treatment schedule of 2 treatment sessions per week over a period of 1 year. The other group was given a treatment schedule of a month of intensive, twice a day treatment followed by treatment twice a week for 5 months. Children undergoing the shorter, more intensive form of treatment showed the greatest gains in motor function showing that once again, a short, intensive program was superior to a longer, less intensive program.

When designing practice schedules, another aspect to consider is the amount of feedback that is given to the subject during a training session. Feedback is an important factor in motor learning and is necessary for the retention of motor skills [18]. Inherent or intrinsic feedback is supplied by the body's own proprioceptive and visual inputs [180]. During treatment augmented feedback can be provided in addition to inherent feedback as was mentioned in the paragraph on Biofeedback [18]. There are two types of augmented feedback that may be utilised in Physiotherapy treatment: knowledge of results (KR) and knowledge of performance (KP) [18]. Knowledge of results refers to feedback about the movement outcome in relation to the task goal [18]. Knowledge of performance refers to feedback about the kinematics or strategies of movement chosen during a movement trial [18]. In adults, KP was found to be more beneficial for skill learning than KR [18]. A study by Thorpe et al (2002) showed that children with cerebral palsy are also able to make use of KP during motor skill acquisition[18] but the optimal parameters are still unknown.

Apart from the type of feedback provided, the amount of feedback has also been found to influence motor learning [180]. Reducing feedback during practice is thought to increase information processing demands during practice and therefore improves retention of skills [180]. Adults were found to perform better on retention tests following reduced feedback practice [180]. Children however differ from adults in their information processing strategies. A study by Sullivan et al (2008) showed that typically developing children require longer periods of practice and a more gradual reduction in feedback when compared to young adults [180]. If knowledge of results feedback is reduced too quickly, it increases the cognitive effort required for motor skill acquisition in children [180].

The Nintendo Wii Fit balance board provides KP and KR during gaming. KP is supplied throughout gaming as the player sees the avatar reacting and moving on screen in response to his own movement.

University of Cape Town

Figure 2: Nintendo Wii Soccer – force plates translate COP changes into movement of the Avatar

http://gadgets.fosfor.se/wii-fit/ [181]

Movement strategies can therefore be adapted during gaming in order to adjust to gaming requirements. KR is supplied at the end of each 2-4 minute period of gaming as the child's performance is scored at the end of each trial. The disadvantage with this type of gaming technology is that KP and KR cannot be adjusted or reduced in terms of their frequency. They remain constant throughout gaming. Seeing as a reduction in KR has been found to be beneficial for skill retention in children, a constant supply of KR may limit the child's ability to retain new motor skills gained through gaming. This limitation should be taken into account when considering the Wii Fit as a form of rehabilitation.

In summary, research has shown that shorter periods of intensive, block therapy may be more beneficial than extended periods of less intensive therapy [179] for children with cerebral palsy. The type and amount of feedback given should be considered when planning an intervention. Children with cerebral palsy have been shown to benefit from

University of Cape

augmented feedback but the optimal parameters of feedback have not yet been established [18].

2.5 Outcome measures

2.5.1 Classification and Psychometric properties

The quality of a measurement instrument is generally described in terms of its psychometric properties. All standardised outcome measures report reliability and validity. Reliability refers to the constancy of the test to give repeatable measures and validity refers to the ability of the instrument to measure what it is intended to measure [182]. The quality of an outcome measure however depends on a third quality as well, namely its responsiveness. Responsiveness refers to the ability of the test to detect change over time if it has taken place [183].

The terms outcome measure and health-status measure are often used interchangeably although they are not the same [184]. Health status measures are discriminative or predictive indices and are developed to cross-sectionally detect differences between individuals or groups at one point in time [184]. Outcome measures are evaluative indices and are developed to detect change within individuals or groups longitudinally [184]. Therefore outcome measures serve to evaluate the effectiveness of interventions by reflecting change over time.

Measurement instruments may faciliate the observation of intra-subject or inter-subject variation. Norm referenced tests are used to compare an individual's motor performance in relation to the performance of a representative population group. Criterion referenced tests are used to evaluate an individual's performance against his own previous performance or a uniform set of skills over time [185].

University of Cape Town

In addition to the abovementioned properties, the feasibility and clinical utility have to be taken into account [184] when choosing an outcome measure. The clinician has to assess whether the instrument includes desired domains and outcomes to be tested (content validity) and whether or not these will be responsive to change for the particular population in question [184]. For instance, responsiveness to change may be restricted by floor and ceiling effects. If the outcome measure is too difficult for the subject in question, a floor effect will be seen [186]. This implies that the subject's score remains unchanged at the bottom of the scale because outcomes are too difficult for the subject to perform [186]. If the outcome measure is too easy for the subject then a ceiling effect will occur [186]. This implies that any improvement in the subject's score may not be measured seeing as their score is already at the very top end of the scale [186]. Although good reliability, validity and responsiveness are desirable in all outcome measures, sometimes a trade-off has to be made between psychometric properties and practicality of use [184].

The ICF requires the clinician to assess the child in dimensions of impairments, activity limitations and participation restrictions. Outcome measures are generally designed to test a specific aspect of the patient's health. In the following section, the outcome measures considered for this study are divided accordingly into categories of impairment, gross motor function and health-related quality of life.

University of Cape Town

2.5.2 Measuring Impairment

2.5.2.1 Balance

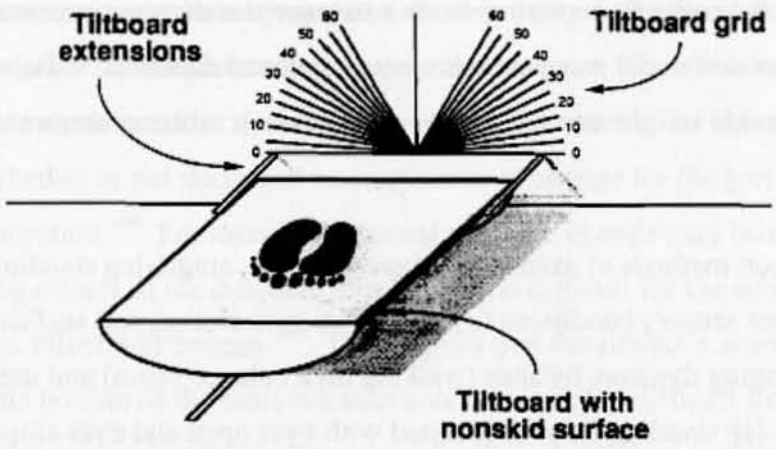
A standardised outcome measure should be used to accurately assess whether the treatment of balance and postural dysfunction has been successful. However, few reliable and comprehensive balance measures exist to date [4]. Studies investigating the psychometric properties of standardised balance tests have yielded disappointing results. The performance of children on balance tasks appears to fluctuate from one session to the next [4]. In addition to this, few balance tests examine all three aspects of balance control: steady state, reactive postural control and anticipatory postural control. As a

result, the patient's performance on a balance test does not necessarily reflect his performance under more complex environmental demands [81]. Balance tests generally do not provide insight into the quality of movement or the strategies of movement used [81].

Common methods of assessing balance include: single-leg standing, standing under different sensory conditions (eyes open vs eyes closed, soft surface vs hard surface) challenging dynamic balance (walking on a balance beam) and use of a tilt board [4]. Single-leg standing balance is tested with eyes open and eyes closed. The subject is placed barefoot 2 feet from a visual target on a wall in front of him and is asked to put the hands on the hips and raise one foot off the ground. Timing is started as soon as the foot leaves the ground [187]. Timing is stopped when the free foot touches the ground, the hands leave the hips, or when the supporting foot moves from its original position [187]. When testing the eyes-closed condition, the same criteria as above apply but timing may also be stopped as soon as the subject opens the eyes [187]. Test re-test reliability for the eyes-open condition was found to be high (.91-1.0) while test-retest reliability for the eyes-closed condition was lower (.59-.77) [187].

The tiltboard tip test requires the subject to stand with the feet together on marked footprints in the centre of an 18 by 18 inch tiltboard [187]. The tiltboard has angle markers that extend 4 inches from the tiltboard to the wall. A chart from 0-60 degrees is mounted on the wall behind the tiltboard.

University of Cape Town



Atwater et al (1990) [187]

An examiner then tilts the board carefully and a second examiner takes readings from the chart as soon as a postural adjustment is seen e.g. removing hands from the hips, stepping forward or sideways or requiring help to prevent a fall. The Tiltboard Tip Test was found to have good inter-rater reliability (rho = 0.98) but was found to have poor test-retest reliability (rho = .45) in children with and without disability. This form of equipment is also not readily available to all physiotherapists [4].

One tool that measures balance at the level of impairment is the Pediatric Clinical Test of Sensory Integration for Balance (P-CTSIB) [3]. P-CTSIB was derived from the Clinical Test of Sensory Interaction for Balance [3]. The P-CTSIB is used to assess the contributions of sensory information to standing balance in children [3]. Postural sway is investigated under 6 different sensory conditions: 1) eyes open, standing on a hard, flat surface 2) eyes closed, standing on a hard, flat surface 3) eyes open, standing on a medium density foam 4) eyes closed, standing on a medium density foam 5) eyes open, standing on a hard, flat surface with a visual conflict dome over the head 6) eyes open, standing on a medium density foam with a visual conflict dome over the head [3]. The P-CTSIB has shown fair to good inter-rater reliability (rho = 0.67-0.92) but has shown low to moderate test-retest reliability (.45-.78) [3]. Some of the Items on the P-CTSIB also

University of Cape Town

showed a great learning effect and were therefore not deemed suitable for balance testing in children between the ages of 4-9 years [4].

Another tool that assesses balance and postural stability at the level of impairment is the Functional Reach Test (FRT) [3]. The FRT was developed for use in elderly patients but has been used in children with cerebral palsy [3]. During the FRT the subject is asked to reach out as far as possible beyond arm's length while maintaining a fixed base of support in standing. The distance reached is then measured [3]. The intra-rater reliability of the FRT was found to be good (r= .87-.94) but had weak test-retest reliability (r = .31 - .34) when used for children with developmental delay [3]. The FRT is therefore not suitable for the assessment of children with disabilities.

The Berg Balance Scale (BBS) was developed to assess balance in elderly or neurologically impaired subjects [3]. The BBS is performance based and has 14 items. 1) sitting to standing 2) standing unsupported 3) sitting unsupported 4) standing to sitting 5) transfers 6) standing with eyes closed 7) standing with feet together 8) reaching forward with outstretched arm 9) retrieving object from floor 10) turning to look behind 11) turning 360 degrees 12) placing alternate foot on stool 13) standing with one foot in front 14) standing on one foot [3]. The BBS has good inter- and intra-rater reliability (.98 and .99 respectively) [3]. However, the correlation of the BBS and balance parameters measured with laboratory equipment was found to be poor to moderate (.20 - .67) [3]. A study by Khembavi (2000) showed that children with cerebral palsy who are classified at a Level I or Level II on the GMFCS have no difficulty with the items on the BBS [3]. The BBS was not able to discriminate between typically developing children and Level I and II children with cerebral palsy[3]. The BBS scores for these high functioning children demonstrate a ceiling effect [3]. This means that the BBS is not a useful tool for assessing and monitoring the balance abilities of children with spastic hemiplegia.

University of Cape Town

Some Motor Developmental Scales include Balance subtests. Two such scales are the Peabody Developmental Motor Scale (PDMS) and the Bruininks Oseretsky Test of Motor Proficiency (BOTMP) [3 4]. The PDMS is a norm-referenced and criterion referenced motor scale that can be used from birth to five years [23]. As a result, the Peabody was not considered as an outcome measure for this study seeing as subjects would be 7-14 years of age.

The BOT-2 however may be used to test motor proficiency of children with mild motor impairment or developmentally handicapped children between the ages of 4.5-14.5 years [3 4]. The BOTMP was developed as a discriminative health status measure and consists of 6 domains, one of which tests balance. Subtest 5: Balance has been used both in evaluative and discriminative contexts [4 188]. It consists of tests that challenge the subject's standing and walking balance with activities such as single-leg standing, single-leg standing with eyes closed, standing on a balance beam and walking heel-to-toe on a straight line. The Inter-rater reliability of Subtest 5: Balance was found to be high (r = 0.99). Test-retest reliability however differs [187]. Subtest 5: Balance had a moderate test-retest reliability of .61 and .65 for the age ranges of 4-7 and 13-21 years respectively. The test-retest reliability for children aged 8-12 years however, was found to be poor with r = .45 [188]. This implies that Subtest 5 may be unstable when used as an outcome measure for children of this particular age range. Although test-retest reliability has been found to be low to moderate for the balance subtest, each item on the test should be carried out twice in succession with the subject's poorer trial being discarded [188]. The test therefore allows for some variability in performance. The BOT-2 Subtests 5 and 6 will be discussed in further detail in section 2.5.3.

Laboratory methods using technology and computer analysis are the gold standard when measuring balance ability, however these are generally used for research purposes and are rarely accessible to physiotherapists wanting to assess children's balance abilities on a daily basis. As a result, clinicians have to find measures that best suit their needs in terms of practical relevance and psychometric properties. This is currently still a

University of Cape Town

challenge since there are few reliable and standardised outcome measures that are readily available to clinicians for the assessment of balance and postural stability in children with disability. (See table summarising the above-mentioned Balance test on the following page).

University of Cape Town

Table 2: Summary of Balance tests

Measure	Description	Limitations	Reliability
Single leg standing	Tested with eyes open and eyes closed. Subject stands barefoot 2 feet from visual target on wall in front of him. Subjects is asked to place hands on hips. Timing stopped when free foot touches floor, hands leave hips, supporting foot moves from original position or eyes are opened when testing eyes closed condition.		Test re-test reliability eyes open: rho = 0.91-1.0 Test re-test reliability eyes closed: rho = 0.59-0.77
Tiltboard tip test	Subject is required to stand with feet together on marked footprints in centre of 18 by 18 inch tiltboard. The tiltboard has angle markers that extend from tiltboard to wall. A chart from 0-60 degrees is mounted on the wall. An examiner tilts the board and a second examiner takes the readings from the chart as soon as a postural adjustment is seen eg removing hands from hips, stepping forward or requiring help to prevent a fall.	Not readily available to physiotherapists	Inter-rater reliability: rho = 0.98 Test re-test reliability: rho = 0.45
Pediatric Clinical Test of Sensory Integration for balance (P-CTSIB)	Postural sway is investigated under 6 conditions: 1) eyes open, standing on a hard flat surface 2) eyes closed standing on a hard, flat surface 3) eyes open, standing on a medium density foam 4) eyes closed, standing on a medium density medium density foam 5) eyes open, standing on a hard, flat surface with a visual conflict dome over the head 6) eyes open, standing on a medium density foam with a visual conflict dome over the head.	Strong learning effect seen on some of the items and therefore not deemed suitable for balance testing in children between ages 4 -9 years.	Inter-rater reliability: rho = 0.67 – 0.92 Test-retest reliability: rho = 0.45 – 0.77
Functional Reach Test	Subject is asked to reach out as far as possible beyond arm's length while maintaining a fixed base of support in standing. Distance reached is measured in cm.	Developed for use in elderly patients. Low test-retest reliability when used in children with developmental delay. Therefore not suitable for assessment of children with disabilities.	Intra-rater reliability: rho = 0.87 – 0.94 Test-retest reliability: rho = 0.31 – 0.34

University of Cape Town

Berg Balance Scale	14 performance based items: 1) sitting to standing 2) standing unsupported 3) sitting unsupported 4) standing to sitting 5) transfers 6) standing with eyes closed 7) standing with feet together 8) reaching forward with outstretched arm 9) retrieving an object from the floor 10) turning to look behind 11) turning 360 degrees 12) placing alternate foot on stool 13) standing with one foot in front 14) standing on one foot	Designed to assess balance in elderly or neurologically impaired subjects. Correlation with laboratory equipment is poor. Ceiling effect for children at Level I and II on GMFCS therefore not useful for children with hemiplegia.	Inter-rater reliability: rho = 0.98 Intra-rater reliability: rho = 0.99 Correlation of BBS parameters with laboratory equipment: Rho = 0.20 – 0.67
BOT-2 Subtest 5: Balance	Items challenge standing and walking balance eg single-leg standing with eyes open and closed, standing on a balance beam, heel-to-toe walking on a straight line etc.	Low to moderate test-retest reliability.	Inter-rater reliability: rho = 0.99 Test-retest reliability for children aged 4-7: rho = 0.61 Test-retest reliability for children aged 13-21 years: rho = 0.65 Test-retest reliability for children aged 8-12 years: rho = 0.45

University of Cape Town

2.5.2.2 Spasticity: Modified Ashworth Scale (MAS)

Spasticity is a contributing factor to functional limitations in children with cerebral palsy [189]. The failure of agonist/antagonist inhibition in spastic muscles leads to poor motor function [190] and spasticity should be taken into account when investigating the effectiveness of interventions that aim to improve gross motor function. Spasticity is defined as a muscle's velocity-dependent resistance to stretch [19]. Hypertonia is discussed in section 2.3.1.1. It is defined as a muscle's increased resistance to passive externally-imposed movement or stretch [19 99]. The Modified Ashworth Scale (MAS) is a clinical assessment tool that is widely used to quantify spasticity, muscle tone or resistance to

passive stretch [19]. This is done by moving the patient's joint through range at a standard speed. The resistance to stretch is then rated on a 6 point scale. Velocity of movement is not changed during the performance of the MAS and it is therefore argued that this scale is a better measure of hypertonia than of spasticity [19]. Controversy also exists regarding the reliability of the MAS. Some studies state that inter-rater reliability is poor [191] while others state that the inter-rater reliability is acceptable [192-194].

The Tardieu Scale (TS) is an alternative clinical assessment tool that is often cited to be a more sensitive and appropriate measure of spasticity than the MAS [195 35] because it takes speed of muscle stretch into account [35]. The Tardieu scale however, has limitations of its own as it does not measure spasticity exclusively but also includes a measure of clonus [35]. In addition to this, muscle stretch velocities have not been standardised and the TS is more time-consuming than the MAS [35].

University of Cape Town

2.5.2.3 Joint Range: Goniometry

Joint range of motion is often limited due to spasticity and is therefore also a contributing factor to impairments in functional mobility. Orthopaedic interventions such as Botulinum Toxin injections are usually aimed at improving function by reducing spasticity and increasing joint range of motion [189]. Goniometry refers to the measurement of joint range of motion in geometric angles [196]. Active and passive joint ranges are measured with a 180 or 360 degree protractor with two arms that are joined at an axis, called a goniometer [196]. Joint range can be used as an indicator of muscle shortening, joint contracture or spasticity [197]. It was found that goniometry measurements are valid, reliable and reproducible in children with cerebral palsy if a strict protocol is followed [198 199]. Intra-rater and within-session reliability is generally cited to be higher than inter-rater reliability [200] although a global mean measurement error of intraobserver values has been reported to be as high as 5 degrees (SD = 5 degrees) during ankle range measurements [199]. In this study, active and passive ankle and knee joint range of motion was measured with a goniometer.

2.5.2.4 Weight distribution

As mentioned above in section 2.3.2, patients with hemiplegia tend to bear more weight on the unaffected limb than the affected limb. This uneven weight distribution may lead to disuse atrophy and other secondary impairments. As a result, weight distribution and symmetry is a variable of interest in the rehabilitation of hemiplegic stroke patients or patients with hemiplegic cerebral palsy. Force platforms have been used for the purpose of assessment and treatment of weight distribution deficiencies in hemiplegia [201-203]. Stance symmetry is reported as the percentage of weightbearing on the unaffected leg versus the affected leg. Numerous studies have shown improvements in stance symmetry following biofeedback training using force platforms [201-203]. The Nintendo Wii Fit balance board can be likened to such force platforms since one of its applications is to measure the subject's weight bearing symmetry in standing. Therefore, the Wii Fit has been considered an alternative to the force platforms commonly found in laboratories.

A study by Clark et al (2009) investigated the test-retest reliability and validity of the Wii Fit Balance Board in thirty healthy subjects (average age 23.7 years). According to this study, it was found that test-retest reliability within-device and between-devices was good to excellent with an ICC of 0.66-0.94 and 0.77-0.89 respectively [204]. However other studies seem to contradict these findings. Gras et al (2009) investigated the validity and reliability of the Nintendo Wii Fit body test [205]. Thirty-one subjects between the ages of 18 to 25 years were required to undergo the Nintendo Wii Fit body test twice in succession. Each subject was then required to undergo 2 trials on the Neurocom EquiTest, a research standard test commonly used as a balance assessment tool that is known for its sensitivity, test-retest reliability and validity. Results showed that the Wii Fit left-right symmetry readings were not correlated ($r = .210$, $p = .226$). Data from the EquiTest were compared to the Wii Fit readings and it was found that CoG measurements as distance from origin and forward-backward data were also not correlated ($r = .147$, $p = .300$ and $r = .147$, $p = .171$ respectively). It was concluded that the Nintendo Wii Fit body test is not reliable and that its validity is questionable when

University of Cape Town

compared to the Neurocom EquiTest. The authors conclude that the Nintendo Wii Fit can not be used with the same level of confidence as the Neurocom EquiTest to analyse balance and left-right symmetry.

2.5.3 Measuring Gross Motor Function

There are a number of motor development scales available to physiotherapists. These scales are usually developed for specific population groups in terms of age and motor function and are either criterion referenced or norm referenced. Many of the motor development scales consist of large batteries of tests that take a long time to administer and are impractical for routine use. Children with hemiplegic CP are generally high functioning and need to be challenged during a functional assessment. If the motor scale is too easy, a ceiling effect inevitably occurs [186]. As a result, for this study, functional outcome measures were chosen that would allow monitoring of the functional status of children with spastic hemiplegia, would be relevant and challenging enough to prevent a ceiling effect and would not take too long to complete. What follows is a description of the tests used as well as the alternatives that were considered for this study.

University of Cape Town

2.5.3.1 The Timed Up and Down Stairs (TUDS)

The Timed "Up&Go" (TUG) test is a measure of functional ambulation and dynamic balance [37]. It has been found to be a valid and reliable method for measuring functional balance ability in children with cerebral palsy aged three to 19 years [206 37]. In this test, the subject is required to rise from a chair and walk a distance of three meters to touch a mark on a wall, turn around and return to a seated position at a pace that is comfortable to the patient [37]. The TUG score is measured in seconds from the word "go" to the patient returning to a seated position [37]. Mean TUG scores for Level I and II ambulating children only differ from those of typically developing children by 1 and 3 seconds respectively (SEM = +/- 0.37 and 0.38 respectively) [36]. Therefore it follows, that gait speed is generally not a problem in children with spastic hemiplegia. As a result, it has

been suggested that the TUG may be more appropriate to measure improvements in mobility function in children with more severely impaired mobility [36].

The Timed Up and Down Stairs (TUDS) test was developed as an alternative functional mobility measure that has the potential to reflect improvements in postural control in children with cerebral palsy [36]. Starting at the bottom of a flight of stairs (12-14 stairs with a handrail on one side) the child is asked to "quickly but safely" ascend the flight of stairs, turn around and descend the flight of stairs. The test score is measured in seconds from the word "go" to the point where the child returns to the bottom landing with both feet [36]. The child may use any gait strategy (step-to or step-over-step) and the use of hand rails is permitted as long as the child faces forward while ascending/descending the flight of stairs [36]. The test does not however stipulate whether handrails should be on either side so that the child may use either hand. It has been cited that a timed up and down stairs test is a good reflection of a subject's ability to be active in the community and home during recreational activities [36]. Preliminary reliability and validity of the TUDS has been shown in a study of 8-14 year old GMFCS Level I and II ambulating children with cerebral palsy [36]. The Timed Up and Down Stairs requires a considerable amount of strength in the lower extremities, coordination of fast reciprocal movements, as well as anticipatory and reactive postural control [36]. Although the TUG is more extensively validated and standardised than the TUDS, the latter is more challenging and therefore likely to be a more responsive measure of improvement in postural control in children at Level I and II on the GMFCS [36].

University of Cape Town

2.5.3.2 The Gross Motor Function Measure (GMFM) and the Pediatric Evaluation of Disability Inventory (PEDI)

Several health indices and outcome measures have been developed for the assessment of paediatric motor function. The Gross Motor Function Measure (GMFM) was developed specifically for children with cerebral palsy [14]. The Pediatric Evaluation of Disability Inventory (PEDI) was developed to assess the capabilities of children and adolescents

with disabilities [24]. The GMFM focuses purely on gross motor function whereas the PEDI includes psychosocial and self-care domains.

The Gross Motor Function Measure (GMFM) is widely considered to be the criterion standard functional measure for children with cerebral palsy [37]. Measurement is based on the subject's abilities and limitations in gross motor function [123]. The GMFM has been validated for children with cerebral palsy and has good intra- and inter-rater reliability [207]; [109]. It is responsive when testing for clinically meaningful change in gross motor function [109]. The test consists of 5 domains: A) lying and rolling, B) crawling and kneeling, C) sitting, D) standing, E) walking, running and jumping.

The correlation between GMFCS levels and GMFM scores has been shown to be -.91 [208], therefore subjects at Level I and II can be anticipated to have good scores on Dimensions A)-C). To make the test more responsive, only Sections D (standing) and E (walking, running, jumping) are often used for assessment purposes. This is commonly done to limit the ceiling effect when assessing change in balance control and walking ability in independently ambulating children [121] [209] [108]. In some instances however, finding the Goal Total Score for these 2 dimensions does not compensate for the ceiling effect. Numerous studies investigating the effect of Dorsal Rhizotomies or Botulinum Toxin injections have reported that a ceiling effect in GMFM measures made the test unresponsive to change post-treatment especially in higher functioning children [121] [210]. It has also been noted that the GMFM may not be as sensitive to change as other concurrent measures for example gait parameters after tendon lengthening [121].

The GMFM may also be unresponsive to certain types of skills not sufficiently represented by the items of the test [121]. The GMFM has been suggested to be less sensitive especially in its upper range compared to its middle range indicating a potential non-linearity in the difficulty of tasks across the GMFM item list [211]. This means that the GMFM is most responsive when used to assess the motor function of children who score

University of Cape Town

in the middle ranges of the scale [211] [212]. Buckon et al (2004) suggest that alternative or additional outcome measures be used when investigating the effect of intervention on higher functioning children [212].

A measure that is often used as an alternative to or in conjunction with the GMFM is the Paediatric Evaluation of Disability Inventory (PEDI). The PEDI was developed as an outcome measure for children with disabilities [24]. It consists of 3 parts namely 1) Functional skills (197 items) 2) Caregiver Assistance (20 items) and 3) Modifications (20 items) [24]. Capability is assessed in terms of functional skills that the child can achieve [24]. Level of performance is measured in the amount of caregiver assistance needed in the Caregiver Assistance section [24]. Each of the 3 parts of the PEDI is further subdivided into the categories of Self-care, Mobility and Social Function [24]. The mobility domain includes activities such as floor mobility, ambulation, transfers and mobility in different environments [24]. The inter-rater reliability of the PEDI was found to be high with intra-class correlation co-efficients ranging between .84 – 1.00 [213]. However, critique on the PEDI points out that the motor skill items are limited and all relate to either crawling or walking activities [213]. No mention is made of higher-level functional items such as running and jumping [213]. This means that the PEDI is not an adequate instrument for the assessment of higher functioning children [213]. The authors indicate that the gross motor test items selected were intended to be biased towards children on the lower functioning end of the spectrum [213]. Therefore the PEDI is not suitable for the use of school-aged children at Level I and II on the GMFCS.

University of Cape Town

2.5.3.3 The Bruininks-Oseretsky Test of Motor Proficiency

The BOT-2 was originally developed as a norm-referenced test for typically developing children. Although the BOT-2 is in essence a norm-referenced test, Bruininks and Bruininks (2005) have reported criterion validity between the BOT-2 and other measures of motor performance [5]. Indeed, the BOT-2 has been used as an evaluative and

discriminative test in several studies investigating motor performance and efficacy of interventions in child population groups with a range of disabilities, including CP [4 5].

The Bruininks-Oseretsky Test of Motor Proficiency, 2nd Edition (BOT-2) consists of composites that evaluate 4 different areas of motor function: fine manual control, manual coordination, body coordination, strength and agility [5 188]. These are further broken into eight subtests [188]. Subtest 5: Balance consists of 9 activities that tap into the "balance and motor skills required for successful participation in sports and recreational games" (pg 849) [5]. Subtest 6: Running Speed and Agility consists of 5 activities that "assess running speed and postural control during walking, running and jumping" (pg 849) [5]. Each activity is scored on an ordinal scale using different response categories specific to the activity [5 188].

The inter-rater reliability of the BOT-2 was found to be good with all Pearson product moment correlation coefficients for the subtests and composites being greater than .86 [188 214]. The test-retest reliability was high for the total motor composites with a Pearson product moment correlation coefficient greater or equal to .80 when tested in 3 different age groups. The test-retest reliability of some of the subtests however was found only to be low to moderate. One of these is Subtest 5: Balance. Test-retest reliability for age groups 4-7 and 13-21 had an r of .61 but the r for age group 8-12 was only .45 [188]. This indicates low test-retest reliability for this particular age group. The implication is that the measure may be unstable when used as an evaluative index. The test-retest reliability of Subtest 6: Running Speed and Agility, was higher with r ranging between .88 and .94 for all age bands [188]. Although the test-retest reliability is low to moderate for the Balance subtest, it has been used in numerous studies to assess balance in children with disability or balance disturbances [5 215].

University of Cape Town

2.5.4 Measuring Health-Related Quality of Life

2.5.4.1 The EQ-5D-Y

Children with cerebral palsy cannot be "cured" and it is important to know how treatment and disability affect the child's quality of life [216]. Russo et al (2008), demonstrated that children with hemiplegic cerebral palsy experience reduced quality of life compared with typically developing children [217]. According to Eiser & Morse (2001) Quality of Life assessments should be incorporated when testing new treatment approaches so that informed decisions can be made about whether or not a novel treatment is appropriate [216]. The youth version of the Euroqol questionnaire has been standardised and validated for the measurement of Health-related Quality of Life (HR-QoL) in children [11]. It provides a 5 dimensional profile (EQ-5D-Y) with questions related to the following health domains: mobility, self-care, usual activities, pain or discomfort and anxiety or depression [11]. Every domain has 3 possible responses ranked in order of severity: no difficulty, some difficulty, extreme difficulty [11]. The second part of the questionnaire consists of a Visual Analogue Scale (EQ-VAS) that is used to assess the patient's perception of their health on the day of assessment [218]. An advantage of using the EQ-5D as a HR-QoL measure is its brevity. It consists of 6 questions and takes only a few minutes to complete thereby placing minimal burden on the respondent [219].

University of Cape Town

When measuring HR-QoL in populations whose reliability in responding is questionable either due to poor state of health, cognitive deficits or young age, researchers frequently opt to use proxy reports of Quality of Life whereby a care-giver or family member responds to the HR-QoL questionnaire from the patient's point of view [220 221]. The proxy version of the EQ-5D-Y has been found to be feasible and valid when measuring child QoL [222]. However, due to the subjective nature of Quality of Life, there are strong arguments to support the use of child self-reports whenever possible [216]. Provided that children are given age-appropriate questionnaires, HR-QoL reports of children as young as 6 years old are used independently of their proxy reports [223]. Studies have shown that proxy reports of HR-QoL have low to moderate correlation with child self-reports [223]. Proxy reports agree with child self-reports mostly in the domains that concern

observable characteristics and physical health [223]. Parent reports of the child's health and emotional state are generally worse than child self-reports especially in children with chronic conditions [223]. It is therefore of interest to the researcher to collect patient self-reports wherever possible [219].

2.6 Study designs

The double-blind, randomised controlled trial (RCT) is generally accepted to be the gold standard for experimental research when investigating the effectiveness of an intervention [224]. Such a study design is robust to confounding variables and human bias [224]. Depending on the effect size of the treatment however, the RCT requires a certain number of subjects per treatment and control group [225]. In rehabilitation research, the numbers of subjects available for randomisation to control and treatment groups is often limited. This presents a problem to the researcher because effect size of an intervention generally needs to be large to avoid a Type II error [226]. For this reason, the single-subject research design is often employed in rehabilitation research. Bobrovits and Ottenbacher (1998) consider the single-subject research design to be a clinically and scientifically legitimate alternative to group comparison methods [227].

University of Cape Town

Single-subject research designs may be used to test the effectiveness of treatment in a single subject or a small group of subjects [31]. This design is characterised by repeated measures of a clinically relevant and observable target behavior over a baseline and an intervention phase [31]. Repeated measures allow subjects to act as their own controls [31]. A stable baseline is established with a minimum of three repeated measurements before treatment is introduced [32]. Data may be plotted and examined for differences in trend, level and variability of the baseline and intervention phases. A trend behavior of several data points allows the researcher to make inferences about the effectiveness of treatment and decreases the probability that improvement in the target behavior is owing to chance [31].

With regards to patterns of motor learning during the intervention phase, typically developing children often demonstrate some variability in performance during motor skill acquisition [18]. Motor skill learning ability improves with age as maturation and experience play into the acquisition of new skills [18]. Within- subject as well as between-subject variability is common in single subject research designs [18]. Ottenbacher suggests that within-subject variability should not be treated as an error and should not be eliminated from the data but instead it should be thought of as an important component of motor skill learning [18].

A disadvantage of the repeated measures inherent in single subject research designs is the practice effect that may occur. Practice effects refer to the subjects' systematic improvement in performance that may occur purely due to mastery of the items on the outcome measure [228]. A practice effect due to repeated use of an outcome measures is not desirable in the context of motor learning. In this instance, the practice effect acts as a confounding variable because the researcher cannot distinguish whether improvements seen on the outcome measures are due to the beneficial effects of an intervention or due to the practice effect resulting from repeatedly performing the items on the outcome measure [228]. One way of ruling out a practice effect is to monitor the effect of treatment by means of visual analysis. When changes in outcome measures correspond with onset and cessation of the intervention, then the influence of extraneous variables such as the practice effect can be ruled out to a certain extent [229].

University of Cape Town

The single-subject research design is a quasi-experimental approach [31] and is therefore subject to extraneous variables. To control for extraneous variables, subjects in single subject research designs are randomised to baseline phases of varying lengths [31]. By varying the length of baselines across subjects, analysis of trend lines may be done within subjects as well as between subjects. This allows the researcher to control for the effects of history and maturation [230]. In addition to this, if a similar reaction to treatment is seen at similar points in time, between different subjects, then causal inferences can be made with greater confidence [31]. Multiple baseline designs are often used as an

alternative to the withdrawal design when the outcome behavior under investigation is not expected to return to normal after the intervention phase [230], as is often the case in rehabilitation research. The multiple baseline, single-subject research design is therefore practical and suitable for the purpose of this study.

Relying solely on the analysis of graphed data to make inferences has been proven to be unreliable [31]. However, repeated measures are not independent by nature and the serial dependency of repeated measures limits the choice of appropriate statistical methods to be used in single-subject research design [32 31]. These statistical methods are discussed in the following section.

University of Cape Town

2.7 Statistical analysis

Graphical analysis has traditionally been the principal method of data analysis in single subject research designs. Data points are plotted on a line graph. The researcher evaluates whether there are changes in the data pattern and whether these changes correspond with the onset and cessation of the intervention [229]. Data points are visually analysed in terms of their trend, level and variability during the baseline and intervention phases. Variability refers to the amount of fluctuation in data points, that occurs within or between phases [231]. The change in level refers to the absolute change in level of data points across the phases. This may be expressed as a ratio [231]. Trend, also referred to as the slope, is the line of best fit for each phase in question. This describes the direction of the data points and may be positive or negative [231].

Visual analysis is said to be found in 90% of single subject research studies and this prevalence has remained unchanged between 1978 and 2003 [232]. It is said to be holistic because it can detect trends, patterns and cycles in data, delayed responses and within-phase changes in variability that may not be apparent with statistical analysis alone [232]. However, visual analysis is often criticised because no formal interpretation rules are available to the researcher that might standardise the decision making process when

investigating the efficacy of an intervention [233]. This creates subjectivity and inconsistency among raters [234]. Numerous studies have shown that visual analysis techniques have low inter-rater agreement [231]. Another limitation of solely using visual analysis, is the frequency of type II errors. These are common since an intervention is only deemed successful if the changes in trend, level and variability of the graph are clearly visible to the naked eye [234]. Visual analysis, though useful for judgement about clinical significance, does not produce a statement about statistical significance [229]. Small improvements are disregarded because they may not be apparent with visual analysis alone. As a result, it is commonly accepted that visual analysis should be supplemented by some form of statistical analysis [231].

Parametric statistics require data points to be normally distributed and independent of each other. Single subject research designs are based on repeated measures usually taken in regular intervals. This means that data points are temporally related by nature and are therefore usually auto-correlated and not independent of each other [235].

To investigate whether this is the case, data may be tested for serial dependency [235]. If the data points are found to be free of serial dependency, then Analysis of Variance or similar statistical methods may be employed [235]. However, testing for serial dependency requires a very large number of data points. Single subject research studies rarely meet this criterion and as a result, parametric statistics are generally not suited for the data analysis of single subject research studies [235].

In a review of single subject research studies, Parker et al (2009) found that over 75% of the studies investigated, failed to satisfy one or more of the parametric assumptions to be met when using parametric statistics, namely normality, equal variance, no autocorrelation and independence [1]. The author goes on to comment that given such circumstances, parametric statistics are the "worst choice the researcher can make" since the accuracy of effect sizes could then be challenged [1].

University of Cape Town

According to Campbell (2004), the two statistical approaches that may be used to supplement visual analysis in single subject research designs are regression approaches and non-regression approaches [235]. Regression approaches use linear estimation [235]. Data is de-trended by subtracting predicted values from observed data [235]. Correlations can then be calculated and an adjusted R value can be converted to a *d index* which indicates the standardised mean difference in score [235]. Proponents of the regression approach argue that this method is superior to non-regression methods because a trend as well as changes in slope and intercept can be modeled prior to evaluating treatment efficacy resulting in greater sensitivity to treatment effect [235].

Non-regression methods make a statement about the data point differences by investigating the amount of overlap or non-overlap of the data points between the baseline and intervention phases [235]. Examples of non-regression effect sizes include Percentage of Non-Overlapping Data (PND), Percentage of All Non-overlapping Data (PAND) and Nonoverlap of All Pairs (NAP) [1 235]. Most non-regression methods can be used when working with a small number of data points and do not require data to be normally distributed or independent [235]. Proponents of non-regression methods say that the non-regression effect sizes have a higher agreement with visual inspection than regression methods do [235]. They are also easier to calculate, have greater intuitive appeal and reduce bias when working with a small number of data points [235]. In a review of effect sizes for single subject designs, Campbell found regression calculations to be labor intensive and the results to be difficult to interpret intuitively [235]. In addition to this, regression methods yielded comparable results with non-regression based indicators [235]. Campbell (2004) therefore suggests that there is no good reason to choose regression based analysis over non-regression based analysis when supplementation of visual analysis is required [235].

As mentioned above, there are a number of different non-regression approaches that investigate the non-overlap of data points between phases. The degree of non-overlap between the intervention and baseline phases is seen as an indicator of change in

University of Cape Town

performance [1]. Percentage of Non-overlapping data (PND) yields the percent of treatment data points that do not overlap with the highest or lowest baseline data points [1]. Percentage of All Non-overlapping data (PAND) is defined as the percent of all data remaining after removing the minimum number of data points which would eliminate all data overlap between the intervention and baseline phase [1]. These indices, though commonly used, have certain limitations: There is a lack of known underlying distribution meaning that no confidence intervals can be calculated for PND and PAND [1]. They also have low statistical power when working with small sample numbers [1]. They are considered to be sensitive to human error as they are generally calculated by hand [1]. Non-overlap of all Pairs (NAP) is an index that was designed to remedy the weaknesses of the PND and PAND approaches. NAP "summarises data overlap between each phase A data point and each phase B data point" (pg 358) [1]. For a pair to be considered as non-overlapping, the phase B data point should be larger or smaller than the paired baseline phase A data point [1]. The NAP is the number of data point pairs that show no overlap divided by the total number of data point pairs [1]. In essence, NAP describes the probability that a randomly drawn score from the treatment phase will fall below or exceed a randomly drawn score from the baseline phase [1].

University of Cape Town

The NAP may be calculated by hand but this is somewhat labor intensive and leaves room for human error [1]. Instead, NAP may be considered the same as the Area Under the Curve (AUC) in receiver operator characteristic (ROC) curves [1]. This curve is also known as the sensitivity and specificity curve. NAP therefore does not offer a comparison of baseline and treatment phase means or medians but instead it is an indicator of the location of the entire score distribution of a curve [1]. The NAP index is the AUC output in ROC calculations found in most statistical programs. It ranges from 0-1. If the score ranges from 0-0.499, this indicates a deterioration in performance from baseline to treatment phase [1]. If the score ranges from 0.51 -1 then this indicates an improvement from baseline to treatment phase [1]. If the score is 0.5 exactly, then this indicates a 50% chance that scores from one group overlap the other and data points of the two phases cannot be differentiated i.e. neither an improvement, nor a deterioration has occurred [1]. The NAP index (the AUC output from the ROC analysis) is accompanied

by confidence intervals [1]. This is another advantage that the NAP has over other non-regression analysis methods such as the PND and the PAND since confidence intervals cannot be calculated for these methods.

NAP Interpretation guidelines suggested by Parker and Vannest were based on expert visual judgements of 200 datasets. They define the treatment effects as follows: ranges are 0.5 - 6.5 for a weak treatment effect, 0.66 - 0.92 for a medium treatment effect and 0.93 - 1.0 for a large treatment effect [1]. Where a deteriorating trend is desirable in an outcome measure such as the TUDS test (a decrease in time to completion indicates an improved ability to negotiate stairs), the scoring is inverted. A NAP of 0.5 – 0.35 would be a small treatment effect, 0.34 – 0.08 would be a medium treatment effect and 0.07 – 0.0 would be considered a large treatment effect. These NAP ranges and their confidence intervals can be used to supplement graphical analysis thereby allowing the researcher to evaluate the efficacy of treatment in single subject research designs [1].

Rehabilitation research is often impeded by small sample sizes and weak study designs. The single-subject research design is an option for the researcher to present results clearly and with integrity. Although smaller sample numbers come at the expense of generalisability, treatment effects (or lack thereof) can readily be seen upon graphical analysis and statistical methods, that are intuitive and not too labor intensive, can be used to supplement these graphs.

University of Cape Town

2.8 Conclusion based on the literature review

Children with hemiplegic cerebral palsy are generally able to ambulate independently. However, their movement quality and movement efficiency differs from that of typically developing children. Impairments may lead to increased energy expenditure as well as biomechanical abnormalities that tend to lead to secondary impairments and activity limitations over time. Impairments in postural control contribute to deficiencies in gross

motor function. As a result, it is of importance that postural control interventions be included in the physiotherapy treatment of children with hemiplegic cerebral palsy.

The intervention under investigation, use of the Wii Fit, is consistent with the paradigm shift towards task orientated and goal directed learning that has been taking place in physiotherapy over the past few decades. It is no longer considered essential that postural control precedes movement. Instead, the reciprocal interplay between movement and postural control is increasingly recognised: movement should be encouraged in order to improve postural control and improved postural control in turn promotes efficient movement. It is suggested that postural control activities are best embedded in functional tasks to motivate the patient maximally. Literature on balance control and virtual reality rehabilitation supports investigation of a commercially available gaming system as a rehabilitation tool to improve balance and postural stability.

An extensive body of literature has demonstrated the benefits of shorter periods of high intensity training compared to fewer training sessions over a long period of time. As a result, blocked therapy together with the repeated measures in single subject research designs allow for treatment outcomes to be judged over a relatively short period of time.

Although a randomised controlled trial would be the ideal design to prove the effectiveness of the intervention, the reality of rehabilitation research presents the researcher with "real world" challenges such as small sample numbers, class time tables and school terms. The single subject research design lends itself to the rehabilitation researcher and allows inferences to be made about novel treatments even in the light of such challenges.

Adequate outcome measures for children with hemiplegic cerebral palsy are difficult to find. These children often demonstrate a ceiling effect on the Gross Motor Function

University of Cape Town

measure which is generally considered to be the criterion standard when measuring gross motor function in children with hemiplegic cerebral palsy. Although the BOT-2 was designed for use in typically developing children, the items on this measure represent a skill set that challenges children with hemiplegia. As a result, an adapted version of this test is likely to be more responsive to gains in balance control and gross motor function in these children.

The Nintendo Wii Fit was tested in isolation of conventional therapy in this study, merely to prevent the effects of conventional therapy from masking or enhancing the effects of the Wii Fit training. The Nintendo Wii Fit does not demand functional mobility therefore it is not suggested that Nintendo Wii Fit training replace conventional physiotherapy. However, the balance strategies required are embedded in gaming tasks that resemble real world activities. Therefore it may be anticipated that the possible improvements in postural control strategies required during gaming, translate into gross motor activities. As a result, the Nintendo Wii Fit may be a useful adjunct to conventional physiotherapy treatment. The fields of neuropsychology and gaming technology might be considered to fall outside the physiotherapist's scope of practice. However, it is important to look to other fields of science and embrace novel approaches to treatment for the benefit of the patient. It appears that the rehabilitation community and its patients are eager to embrace the Nintendo Wii Fit as a fun and exciting form of therapy. However, the gains that have been reported on internet sites and forums dedicated to "Wii-habilitation" need to be supported scientifically if the Nintendo Wii Fit is to become a legitimate rehabilitation tool.

Cerebral Palsy is the most common disease of childhood treated by physiotherapists and it would be of interest to determine whether this target group responds to a new form of treatment that is as engaging and child-friendly as the Nintendo Wii Fit. With this study, the researcher hopes to establish whether Nintendo Wii Fit gaming will be beneficial for the balance control and gross motor function of children with hemiplegic cerebral palsy.

University of Cape Town

3. Methodology

3.1 Research design

The research design used in this study was an AB, single-subject research design with multiple subjects, repeated measures and multiple baselines. This research design is commonly used where the researcher has a limited number of subjects and a control group is precluded. [54]. The multiple subjects are matched as closely as possible in age and diagnoses and although the training protocol is uniform, it is spread out in timing of onset so that the end of the intervention phase of one child overlaps with the beginning of the intervention phase of another. Frequent measures act as checkpoints for changes in outcome measures [54]. A stable baseline is established [32] by a minimum of 3 multiple baseline measurements, and this allows subjects to act as their own controls [1]. The repeated measures allow for inferences to be made about treatment effectiveness by analysing changes in trend, level and variability in the baseline and intervention phases [31]. Therefore a control group was not included as subjects act as their own controls.

A single-blind protocol was used in this study. Physiotherapists at the relevant schools randomised subjects to treatment groups and carried out the intervention on behalf of the researcher. This allowed the researcher to be blinded to the subject's commencement and completion of the intervention phase and reduced any bias on her part during the measurement sessions. Randomisation was at the physiotherapists own discretion and was achieved by randomly assigning children to one of two groups: one that started the intervention in the 3rd week of measurement and the other which started the intervention in the 5th week of measurement. All children were assessed once a week for a period of 9 weeks, regardless of group assignment. Children continued their standard physiotherapy regimen during the baseline and post-intervention phases. During the 3 week intervention phase however, children received only the Nintendo Wii Fit training and did not receive conventional therapy. This was necessitated by the ethical need not to remove children from the learning environment for much longer than usual.

University of Cape Town

3.2 Null hypothesis

The primary hypothesis was that a Nintendo Wii Fit intervention of 4 x 25 minute sessions for three weeks would not result in medium to large improvements in balance and gross motor function as measured by the adapted BOT-2 Subtests 5 (Balance) and 6 (Running Speed and Agility) in GMFCS Level I and II, 7-14 year old children with spastic hemiplegic cerebral palsy.

Secondary hypotheses related to the impact of the Wii Fit on functional mobility and quality of life as no medium to large improvements would be seen in these variables when measured by the Timed Up and Down Stairs test and the EQ-5D-Y visual analogue scale respectively.

University of Cape Town

3.3 Participants

The study was restricted to children with spastic hemiplegia. The reasons for testing the intervention on children with hemiplegic cerebral palsy are as follows: The Nintendo Wii Fit skiing and snowboarding games require the player to attain a semi-squat position with the Quadriceps and Triceps surae muscles working eccentrically. Although eccentric strengthening of the lower limb stabilisers is desirable in all children with CP, encouraging a crouched position is undesirable in children with diplegic CP since they tend to adapt a habitual crouched position during standing and walking [115]. Encouraging activities in such a crouched position could be detrimental to the child's normal physiotherapy regimen. As a result children with diplegic cerebral palsy were not chosen as the target group for an intervention with the Nintendo Wii Fit. The study was limited to children with hemiplegic cerebral palsy, thereby making the study sample homogenous with regards to type of CP.

In addition to this, children with hemiplegic cerebral palsy generally tend to bear more weight on their unaffected leg as opposed to their affected leg, leading to secondary

impairments such as disuse atrophy and leg-length discrepancies. The Nintendo Wii Fit requires the player to shift not only their COG but also their COP in order to engage with the gaming equipment. Therefore, it was expected that hemiplegic children would be encouraged to shift their weight onto the hemiplegic leg during Wii Fit gaming. It was hypothesised that stimulating weight shift to the hemiplegic side might improve the postural control, balance abilities and gross motor function of children with hemiplegic cerebral palsy.

There are four schools in the greater Cape Town area that cater for children with cerebral palsy. The researcher contacted the schools regarding the number of hemiplegic children that may be eligible for data collection. Due to the small number of children available, it was decided that homogeneity of the sample would be sacrificed for sample size. All children between the ages of 7-14 years would be included as this range was dictated by the number of children available at the schools. Narrowing the age range would have decreased the sample number. Children younger than seven years were not included in the study as it was anticipated that the cognitive ability of children younger than seven years of age might have limited their ability to engage in Wii Fit gaming.

One of the schools in question focuses on the education of children with severe cognitive delay. It was decided that severe cognitive delay may also interfere with the homogeneity of the sample. Therefore the 10 eligible children at this school were only included in the testing of the researcher's reliability in carrying out the outcome measures and not in the actual study.

Given that the multiple baseline design required at least nine weeks of baseline, treatment and post-treatment time, the researcher only had four school terms to complete her data collection over the period of one year. Only one Wii Fit was available for this study, therefore four was the maximum number of children that could be accommodated per school term. Having more than four children per school term would have severly

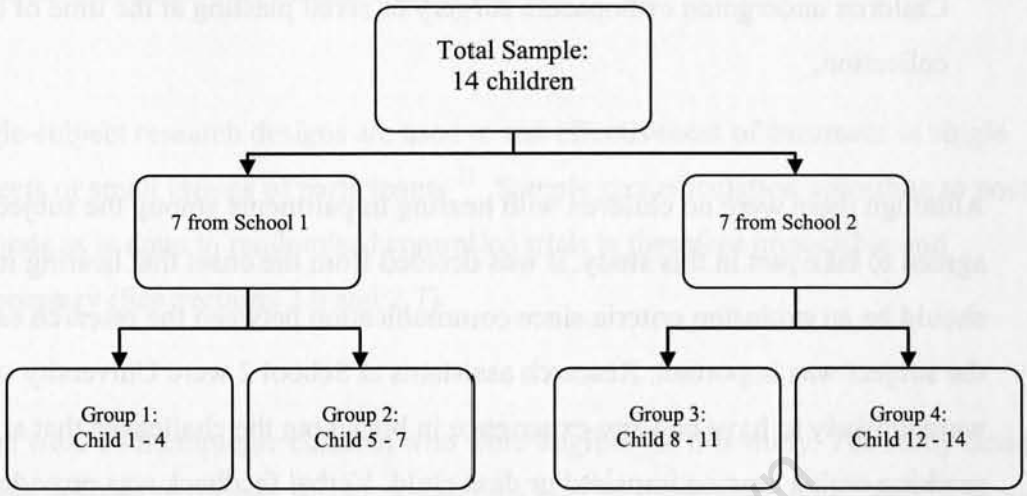
University of Cape Town

diminished the Wii Fit training time per child. Cluster and convenience sampling was used to identify 18 hemiplegic children from two of the schools in the greater Cape Town area who were eligible for the study. Since only 16 children could be accommodated over the course of four school terms, the fourth school that caters for children with cerebral palsy was not approached. Of the 18 children that were found to be eligible at the two schools, the school physiotherapists identified two children with severe behavioural difficulties in the sample. Although behavioural difficulties had not been an exclusion criterion, following the recommendation of the school therapists, it was decided that behavioural difficulties might interfere with Wii Fit training time and might therefore be a confounding factor to the study. Therefore these two children were excluded in order to meet the desired sample number of 16.

Of the 16 participants that were included initially, one child had to be excluded from the study because it was decided that he needed serial plaster casting while another fell ill during the time of data collection. This brought the number of participants to 14. Although more children could have been included from the fourth school that had not been approached for data collection, the availability of one Wii Fit prevented this. Shuttling the Wii Fit between schools from day to day would have been difficult logistically and ultimately would have prevented the researcher from remaining blinded to group assignment. Therefore seven participants were drawn from School 1 and seven participants were drawn from School 2. Children thus identified were assigned to a treatment group by the school physiotherapists.

University of Cape Town

Figure 3: Participant sampling and grouping at School 1 and School 2



3.4 Eligibility criteria

3.4.1 Inclusion criteria

All 7-14 year old children identified by the physiotherapists at the two special needs schools as having spastic hemiplegia and could be classified at Level I and II on the Gross Motor Function Classification System (GMFCS).

3.4.2 Exclusion criteria

The exclusion criteria were discussed with the physiotherapists at the relevant schools. Only children who did not meet any of the exclusion criteria (to the therapists' knowledge) were then considered for participation in this study. The exclusion criteria were as follows:

Children who had a Wii Fit at home.

Children with severe behavioural difficulties.

Children with visual or hearing impairments.

University of Cape Town

Children with epilepsy.

Children undergoing orthopaedic surgery or serial plasting at the time of data collection.

Although there were no children with hearing impairments among the subjects who agreed to take part in this study, it was decided from the onset that hearing impairment should be an exclusion criteria since communication between the research assistant and the subject was important. Research assistants at School 2 were University students who were unlikely to have had any experience in breaching the challenges that arise when working with a hearing impaired or deaf child. Verbal feedback was provided by the research assistants when necessary and in addition to this, the Wii Fit games provide the subject with auditory feedback in the form of chimes or clapping during a successful movement trial. The inability to receive auditory feedback while concentrating on the TV screen may have put children with hearing impairments at a disadvantage.

On the information and consent leaflet, parents were asked to disclose if their child had a Wii Fit at home or if he/she suffered from epilepsy. This further ensured that subjects did not meet any of the exlusion criteria.

University of Cape Town

3.5 Sample size

During the initial planning phase of this study, a post hoc analysis was done to see how many subjects would be needed if a randomised control trial was implemented. The researcher had contacted the Physiotherapists at the relevant schools prior to finalising the study design and was aware that the maximum number of eligible hemiplegic children at the schools in question was far less than the post-hoc analysis required for an RCT to be undertaken. Therefore it was decided that an RCT was not an option, since such a study would have been severely underpowered. The single subject research

design was implemented instead as it allows the researcher to make inferences on treatment outcomes with smaller sample numbers.

Single-subject research designs are used to test effectiveness of treatment in single subjects or small groups of participants [31]. Sample size calculation according to post-hoc methods as is done in randomised controlled trials is therefore impossible and unnecessary (See sections 2.6 and 2.7).

There were 18 hemiplegic children who were eligible for this study. The study design and the availability of one Wii Fit limited the maximum number of children to be treated to 16 during the time available for data collection. Following the exclusion of two participants, 14 participants completed the study (see section 3.3 for details regarding reasons for exclusion).

University of Cape Town

3.6 Instrumentation

In the following section, the outcome measures that were considered and eventually used in this study are discussed. The rationale for using these outcome measures and the adaptations that were made to suit children with hemiplegic cerebral palsy are also presented.

3.6.1 Functional Mobility: The Timed Up and Down Stairs test

The Timed Up and Down Stairs (TUDS) test was developed as a functional mobility measure that has the potential to reflect improvements in postural control in children with cerebral palsy [36]. Starting at the bottom of a flight of stairs (12-14 stairs) the child is asked to "quickly but safely" ascend the flight of stairs, turn around and descend the flight of stairs. The test score is measured in seconds from the word "go" to the point where the child returns to the bottom landing with both feet [36]. The child may use any

gait strategy (step-to or step-over-step) and the use of hand rails is permitted as long as the child faces forward while ascending/descending the flight of stairs [36]. Preliminary reliability and validity of the TUDS has been shown in a study of 8-14 year old GMFCS Level I and II ambulating children with cerebral palsy (see section 2.5.3 for details) [36].

3.6.2 Balance and Gross Motor Function: The Bruininks-Oseretsky Test of Motor Proficiency (BOT-2)

The BOT-2 is designed to be used as a norm-referenced scale in typically developing children. It has however been used in numerous studies as a criterion-referenced scale to test the motor function of children with CP [236-238]. This means that children's scores are not compared to norm-referenced scores but rather each child's score is compared to his own set of scores, as was the case in this study. The BOT-2 can be scored in 4 different ways, one of which is to complete only a subtest that is of interest to the physiotherapist [188]. Subtest 5: Balance and Subtest 6: Running Speed and Agility were chosen for the purposes of this study since these consisted largely of activities that hemiplegic children have been found to struggle with when completing the GMFM Sections D and E (see section 3.7.4 for details on the inter-rater reliability testing of the GMFM). The activities in Subtest 5 and 6 are fewer and more challenging than those in the GMFM Sections D and E. It was anticipated that this scale would therefore be more responsive to change in children than the GMFM, which usually results in a ceiling effect in children with hemiplegic cerebral palsy [121].

A matter of concern when using the BOT-2 Subtest 5 is that the test-retest reliability has been reported to be moderate to poor ($r = .45$-$.61$) [188]. As mentioned above, the researcher often has to make a decision with regards to practicality of the outcome measure even if the psychometric properties of the measure are less than ideal. Upon review of other balance and gross motor function measures, it was decided that the BOT-2 was the most applicable and appropriate balance measure for children with hemiplegic cerebral palsy since the items were thought to be sufficiently challenging to

University of Cape Town

prevent the ceiling effect that is commonly seen when using the GMFM. The BOT-2 was also appropriate in terms of age ranges and the items of subtests 5 and 6 are short enough to complete within half an hour. Therefore the BOT-2 was chosen as the primary outcome measure to test balance and gross motor function in this study.

The manual for the BOT-2 stipulates that single-legged activities such as hopping and balancing should be carried out with the child's preferred leg however, children with hemiplegia are known to have greater difficulty weight bearing on the affected leg. The researcher therefore adapted Subtests 5 and 6 to include activities performed with the hemiplegic leg. For each activity that was performed with the unaffected (preferred) leg, the child was asked to perform the same activity with the hemiplegic leg. The subtest scoring was then adapted to include the same range of raw and point scores for the hemiplegic leg as for the unaffected leg (see example of adapted Subtest 5: Balance scoring sheet on following page and Appendix 8.8 for Original BOT-2 scoring sheet). The total point score was then adjusted by adding the maximum attainable point scores for each item. This meant that the Total Point Scores for the adapted Subtest 5:Balance and Subtest 6: Running Speed and Agility were 52 and 72 respectively.

University of Cape Town

Table 3: Adapted Version of Subtest 5: Balance of the BOT-2 (children with hemiplegia)

Activity	Trial 1	Trial 2							Point Score
1) Standing with feet apart on a line – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
2) Walking Forward on a line	steps	steps	Raw	0	1-2	3-4	5	6	
			Point	**0**	**1**	**2**	**3**	**4**	
3) Standing on **Unaffected Leg** on a line – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
4) Standing on **Affected Leg** on a line – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
5) Standing with feet apart on a line – Eyes Closed	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
6) Walking forward Heel-to-Toe on a line	steps	steps	Raw	0	1-2	3-4	5	6	
			Point	**0**	**1**	**2**	**3**	**4**	
7) Standing on **Unaffected Leg** on a line – Eyes Closed	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
8) Standing on **Affected Leg** on a line – Eyes Closed	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
9) Standing on **Unaffected Leg** on a balance beam – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
10) Standing on **Affected Leg** on a balance beam – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
11) Standing Heel-to-Toe on a balance beam	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
12) Standing on **Unaffected Leg** on a balance beam – Eyes Closed	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
13) Standing on **Affected Leg** on a balance beam – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
Total Point Score:									**/52**

University of Cape Town

In the original version of the Balance subtest of the BOT-2 (see Appendix 8.8), the child is asked to stand with both hands on the hips (wing standing) during the single leg standing tasks while looking at a visual target on the wall. The balance trial is terminated as soon as the free foot touches the floor, the hands leave the hips, or the supporting foot

moves from the original position. Timing is also stopped if after two warnings, the subject hooks the free leg behind the supporting leg or drops the free leg below 45 degrees of knee flexion or looks away from the visual target. However, children with severe upper limb spasticity are often unable to maintain wing standing due to a lack of muscle control and range of movement in the hemiplegic arm.

The same applies to the hemiplegic leg – standing on the unaffected leg requires the affected knee to be flexed. Paresis or spasticity in the hamstrings as well as poor proprioception may prevent the child from maintaining the required knee flexion angle of 45 degrees throughout the trial. It was therefore decided that a trial would only be ended if the free foot touched the floor or if the supporting foot moved from the original position. The visual target was offered for support but looking away from the target was not considered reason enough to stop a trial. During the items where the participant was required to balance with the eyes closed, opening the eyes was however seen as a criterion to terminate a trial. In summary, timing was stopped when the child moved the supporting leg, when the free foot touched the floor or when the eyes were opened during "eyes-closed" items. The child therefore had the freedom to employ any balance strategies available to him/her in order to maintain a single leg standing position. Adapting the criteria for termination of a trial also meant that the balance test was more directly related and specific to the balance reactions and movements that children use when playing the Nintendo Wii Fit games. During gaming on the balance board, the hands are not required to stay on the hips and the player is free to use any balance strategies that suit him or her. It was therefore decided that making the balance test more permissive and lenient to a range of balance strategies might also make it more responsive to the skills learnt on the Wii Fit Balance board.

University of Cape Town

3.6.3 Weight Distribution: The Wii Fit body test

The applications of the Nintendo Wii Fit balance board include a body test that measures the subject's Centre of Pressure (COP) and symmetrical weight distribution. The symmetrical weight distribution is expressed as a percentage on the television screen and the centre of pressure trajectory is shown by means of a line drawing. COP sway has been found to be a good indicator of postural stability and balance control [8]. Had this application been reliable, it would have allowed the researcher to investigate whether COP sway is reduced and whether weight distribution becomes more even as treatment progresses. The stability and test-retest reliability of the Nintendo Wii Fit Body test as an outcome measure were investigated in June 2009. The researcher asked 10 Hemiplegic children to undergo the Wii Fit balance tests twice in succession to see how well the tests correspond numerically from one measurement to the next. During the Wii Fit body test, the child is required to stand still on the balance board for 8 seconds while the foot sensors measure the weight distribution between the right and left leg during quiet standing. In some cases, the difference in symmetrical weight bearing differed more than 15% from one trial to the next (see section 3.7.4). Since quiet standing is not a challenging or complex task that requires practise, it was surprising to see that children had such discrepancies in weight bearing symmetry from one standing trial to the next. At the time that data collection commenced, there was no literature available on the validity and reliability of the Wii Fit Balance Board for the assessment of standing balance. Since then however, a study by Gras et al (2009) supports the researcher's findings that the Nintendo Wii Fit is not reliable as an outcome measure for monitoring weight distribution (see section 2.5.2.4) [205]. Based on the researcher's own findings, it was decided, when testing children with CP, a difference of 15% from one trial to the next showed too great a variability in test outcome and that the Nintendo Wii Fit body test would not be a reliable outcome measure to test for symmetrical weight bearing and balance in children with cerebral palsy.

University of Cape Town

3.6.4 Spasticity and Muscle Tone: The Modified Ashworth Scale

The Modified Ashworth Scale (MAS) is a clinical assessment tool that is widely used to quantify spasticity, muscle tone or resistance to passive stretch. This is done by moving the patient's joint through range at a standard speed. The resistance to stretch is then rated on a 6 point scale [19]. The MAS has been cited as a valid and reliable measure of spasticity [193 194]. Spasticity and increased tone in the Gastrocnemius, Quadriceps and Hamstrings of participants was assessed by the researcher upon first baseline measurement. This was done to investigate whether there was an association between level of impairment and treatment outcome. The intervention under investigation did not aim to reduce spasticity therefore no further measures of spasticity were taken once a baseline measure had been recorded.

University of Cape Town

3.6.5 Joint Range of Motion: Goniometry

Joint range was measured with a goniometer to investigate whether there was an association between level of impairment and treatment outcome. Knee and ankle range of motion was measured in all participants upon first baseline measurement. Intra-observer measurements have been shown to result in global mean measurement errors of 5 degrees (SD 5 degrees) [199]therefore an average of three readings was recorded. The intervention under investigation did not aim to improve knee and ankle range of motion therefore no further measures of these ranges were taken once a baseline measure had been taken.

3.6.6 Health Related Quality of Life: The EQ-5D-Y VAS

The EQ-5D-Y questionnaire is a generic questionnaire that has been standardised and validated for the measurement of Health-related Quality of Life (HR-QoL) in children [218 11]. It provides a 5 dimensional profile (EQ-5D-Y) with questions related to the following health domains: mobility, self-care, usual activities, pain or discomfort and anxiety or depression [218 11]. The second part of the questionnaire consists of a Visual

Analogue Scale (EQ-VAS) that is used to assess the patient's perception of their health on the day of assessment [218]. The EQ-5D-Y has been found to be feasible and valid to elicit self-reports as well as proxy-reports of HR-QoL in children [221] [222]. The EQ-5D-Y only takes a few minutes to complete and therefore places minimal burden on the respondent due to its brevity [219]. Each week, an EQ-5D-Y questionnaire was completed along with the BOT-2 subtests. As some of the five domains overlapped the information gained from the Running Speed and Agility measure and there was little variability in the other domains, only the visual analogue scale of the EQ-5D-Y was used in the statistical analysis to provide an overview of the child's general well-being.

3.6.7 Inter-rater reliability in performing the outcome measures

The researcher's competence and reliability in performing the outcome measures was tested prior to data collection. A third special needs school in Cape Town was approached for this purpose. Only five hemiplegic children were eligible according to the inclusion criteria and the researcher therefore decided to include six of the hemiplegic children at School 2 for a total of 11 children. The schools were visited on two separate days. The researcher and a paediatric physiotherapist rated children simultaneously. First, children were asked to remove their shoes, socks and AFO's. Those who were not in shorts were asked to roll their pants up to knee level. The children were then asked to lie on a mat while the researcher and the second physiotherapist took turns in scoring the children according to the Modified Ashworth Scale. Each child's hemiplegic leg was tested for hypertonia and spasticity in the Hamstring, Quadriceps and Triceps surae muscle groups. The raters recorded their measurements on scoring sheets.

The original Ashworth Scale was designed as an ordinal scale with five categories (0,1,2,3,4). The Modified Ashworth Scale proposed by Bohannon and Smith (1987) includes an additional measure of 1+ [239]. Literature on the MAS-Bohannon scale states that due to ambiguities related to the additional measure, the scale can only be regarded

University of Cape Town

as nominal [240]. The difference between a 1 and a 1+ is that minimal resistance should be felt at the end of range when awarding the former and minimal resistance should be felt in less than half of the remainder of the range when awarding the latter [240]. When awarding a 2, a more marked increase in muscle tone through most of the range should be felt [240]. Upon analysis of the data, the inter-rater reliability was found to be poor. Further inspection revealed that most of the discrepancies between the raters' measurements were as a result of the ambiguity of the1/1+ measure. It was therefore decided that the 1 and 1+ measures would be amalgamated to a score of 1 and any increase in resistance towards the end of range would be scored as a 1. Agreement was defined as two scores being the same or within .5 of each other. Reliability of the MAS was defined as a significant correlation as found by using Cohen's Kappa.

After amalgamating the 1 and 1+ scores, 9 of the 11 Quadriceps scores were in complete agreement and the remaining two were only one grade apart. Cohen's Kappa was 0.542 with a p value of 0.072. Seeing as the p-value was not significant for the Quadriceps, the researcher's reliability for the Quadriceps group may be questioned and results for this muscle group should be interpreted with caution.

University of Cape Town

Table 4: Inter-rater reliability for the MAS scores of the Quadriceps muscle group

Quadriceps rating	Rater 2 = 0	Rater 2 = 1	Row Totals
Rater 1 = 0	7	1	8
Rater 1 = 1	1	2	3
All Groups	8	3	11

8 of the 11 Hamstring scores were in complete agreement with 3 being 1 grade apart. Cohen's Kappa was 0.56 with a p value of 0.010.

Table 5: Inter-rater reliability for the MAS scores of the Hamstring muscle group

Hamstring rating	Rater 2 = 0	Rater 2 = 1	Rater 2 = 2	Row Totals
Rater 1= 0	2	2	0	4
Rater 1= 1	1	4	0	5
Rater 1= 2	0	0	2	2
All Groups	3	6	2	11

All of the Triceps Surae scores were in complete agreement with Cohen's Kappa being 1.00 accompanied by a p value of 0.000.

Table 6: Inter-rater reliability for the MAS scores of the Triceps surae muscle group

Triceps Surae Rating	Rater 2 = 0	Rater 2 = 1	Rater 2 = 2	Rater 2= 3	Row Totals
Rater 1= 0	1	0	0	0	1
Rater 1= 1	0	6	0	0	6
Rater 1= 2	0	0	3	0	3
Rater 1= 3	0	0	0	1	1
All Groups	1	6	3	1	11

University of Cape Town

Cohen's Kappa p-values for the Hamstring and Triceps Surae muscle groups were both significant therefore the researcher was deemed reliable in carrying out the MAS testing of these muscle groups.

Initially it was thought that the GMFM would be the primary outcome measure for this study. Therefore, after both raters had scored the child according to the MAS, the GMFM Sections D and E were completed with each child. Raters took turns in demonstrating and instructing children through the activities while scoring each child for all the activities at the same time but independently of one another.

Upon data analysis, a Goal Total Score was calculated for each child. This Goal total Score is expressed as a percentage. Reliability of the user in this research setting was defined as having no items with more than 5 % difference between the raters and a Spearman's rank correlation of more than 0.9. 5 of the 11 scores were in total agreement and the highest % difference between those that were in disagreement was 2.1%. Spearman's rank correlation co-efficient was 0.94 ($p < .001$). Although inter-rater reliability of the GMFM measure was high, it was noted that most of the activities in the GMFM sections D and E were not challenging enough to be used as an outcome measure for hemiplegic children functioning at GMFCS levels I and II. A definite ceiling effect was seen upon data analysis with the mean Goal Total Score being 92%. This meant that the GMFM Sections D and E would not be responsive to change if used as an outcome measure in this study. Activities that children struggled with were: Item 57/58 (standing on the hemiplegic leg), Item 80 (jumping 30cm high with both feet simultaneously) and Item 82/83 (hopping on the hemiplegic leg). It was decided that a more challenging and therefore responsive outcome measure would have to be utilised for the assessment of gross motor function in this study.

University of Cape Town

After the GMFM sections D and E had been completed, each child was asked to stand on the Wii Fit balance board to carry out the Wii Fit Body Test. The test-retest reliability of the Wii Fit Body Test had to be assessed to determine whether this test would be a reliable outcome measure. The Wii Fit Body Test requires the subject to stand still on the balance board for 8 seconds while the subject's symmetrical weight bearing and the centre of gravity are measured. Symmetrical weight bearing is expressed as a percentage of weight bearing distributed between the right and left leg. Together the readings add up to 100%, the ideal being that each leg carries 50% of the weight (the leg that has the higher percentage reading is the leg that the subject favors for weight-bearing). The centre of gravity is shown as a dot on a grid, the ideal being if the dot is in the centre of the grid. Any deviations from the centre are meant to indicate unequal weight distribution and inadequate posture. Each reading was done twice in succession. Once

the first reading had been taken and recorded, the participant was asked to step off the balance board, the Body test was re-set and the test was repeated.

Data analysis showed that the Spearman's rank correlation co-efficient for test-retest measures was .77. The mean percentage difference between reading 1 and 2 was 6.4 % but percentage differences were extremely variable with the largest percentage difference between reading 1 and 2 being 17.6%. Had the task been a difficult one, that required practise and proficiency, one might have assumed that the child's balance ability would have been the reason for the large discrepancy in successive readings. However, quiet standing is not a challenging task and such discrepancies in weight distribution should not be expected if subjects are given the same instructions each time. It was thought unlikely that the child's weight distribution should change so dramatically from one trial to the next. It was therefore decided that the Wii-Fit body test would be unreliable as an outcome measure and would not be used as such.

The ceiling effect that was found during GMFM testing necessitated the replacement of this outcome measure. It was decided that the Bruininks-Oseretsky Test of Motor Proficiency 2nd Edition (BOT-2) would be used instead of the GMFM sections D and E. Subtest 5: Balance and Subtest 6: Running Speed and Agility of the BOT-2 consist largely of activities that were found to be challenging for the hemiplegic children when performing the GMFM Sections D and E. The BOT-2 subtests were adapted for the use in hemiplegic children (for details on the adaptations made, see paragraph on the BOT-2 under 3.6.2).

The researcher's reliability in performing the adapted versions of the BOT-2 Subtests 5 and 6 had to be tested. At the time, schools were closed due to school holidays and the researcher approached an orphanage to carry out the reliability study with children who would be present during the school holidays. The researcher was accompanied by a paediatric physiotherapist on a day that was suitable for the institution. Six able-bodied

University of Cape Town

children were asked to complete the adapted BOT-2 Subtests 5 and 6 while both the researcher and the physiotherapist scored children simultaneously. Once the third school term had begun, four hemiplegic children from School 1, who would start the intervention 12 weeks later, were asked to perform the subtests while both raters assessed them. This was necessary to ensure that the adapted subtests of the BOT-2 would be feasible outcome measures for children with hemiplegia. With regard to the inter-rater reliability, for Subtest 5: Balance, no case had a difference of more than 4% between the raters (rho = .97, $p < .001$). With regard to Subtest 6: Running Speed and Agility, no case had a difference of more than 5% between the raters (rho = .99, $p < .001$). Inter-rater reliability was therefore considered to be high and the researcher was deemed reliable in carrying out the outcome measures.

University of Cape Town

3.7 Procedure

3.7.1 Assessing the feasibility of this study

In April 2009, the feasibility of this study was tested. Upon arrangement with the physiotherapists at School 1 and School 2, the researcher brought the Wii Fit and a television set to the schools. Two children with hemiplegia from each school were asked to play the Nintendo Wii Fit balance games during their physiotherapy session. Three of the four children were included in the official study later on, however children had only played for 10 minutes each and four months had passed before the first child was required to commence Wii Fit training again. Therefore the trial sessions were unlikely to have influenced the results.

These initial trial sessions allowed the researcher to gain insight into the abilities and performance of children with hemiplegic cerebral palsy when playing the Nintendo Wii Fit games. It also gave the researcher an indication as to which balance games would be most valid and feasible to use for children with hemiplegic cerebral palsy.

3.7.2 Research setting

Data collection took place at two special-needs schools in Cape Town that cater for children with cerebral palsy. School 1 is an English-medium government school in an upper middle class suburb of Cape Town. School 2 is an English-medium government school in a lower middle class suburb of Cape Town. The catchment area is however wider than their geographical location. Although children are encouraged to study the mainstream curriculum that is taught in public schools, remedial teaching may be required following assessment from a multi-disciplinary team (psychologists, occupational therapsists, speech therapists, physiotherapists, teachers, nurses). School 1 and 2 accept children with learning difficulties, however they do not cater for children with severe cognitive delay (these children are catered for by other schools and institutions). Physiotherapy services are offered during school time on an individual or group basis depending on the specific needs of the particular learner and availability of space on the therapy roster. Rehabilitation is largely NDT based. The school year runs from January to December and there are four school terms in a year consisting of nine weeks each. Data collection took place over four school terms from July 2009 – July 2010. There were 18 eligible participants and of these, eight were attending School 1 and ten were attending School 2.

University of Cape Town

3.7.3 Gaining access

Ethical approval was obtained from the Research Ethics Committee of the University of Cape Town. Consent to carry out the study in the relevant public schools was granted by the Department of Education. Thereafter, each school principal was given a synopsis of the research proposal. After permission to carry out the intervention was obtained from the school principals, the researcher sent information leaflets and consent forms to all 18 eligible participants and their parents/legal guardians. Information leaflets and consent forms were either in English or Afrikaans depending on the home language of the participant. No child, parent or legal guardian refused consent. This meant that all 18

children were allowed to participate in this study (see section 3.3 for details regarding reasons for exclusion of some of the participants).

3.7.4 Preparation and training of research assistants

At School 1, the school physiotherapists carried out the intervention on behalf of the researcher while physiotherapy students and a research assistant carried out the intervention at School 2 (for the sake of clarity, these physiotherapists and physiotherapy students will be referred to as research assistants in the sections below). The researcher informed all parties concerned of the study design and the intervention program. On commencement of data collection in July 2009, the research assistants at School 1 were familiarised with the Nintendo Wii Fit. Each assistant was asked to play a few Wii Fit games so that adequate feedback and facilitation could be given to the child during the first few sessions of gaming. This also ensured that the intervention could begin immediately after the baseline measurements had been taken. The same was done with the assistants that carried out the intervention on behalf of the researcher at School 2 in March-May 2010.

University of Cape Town

Research assistants were then required to monitor the Nintendo Wii Fit gaming during the intervention phase. Monitoring of gaming included: ensuring that each child received the required number of treatment sessions per week; operating the Wii Fit remote control to choose and reset the balance games; staying in the close vicinity of the child as a safety measure; guiding the child verbally and with some facilitation through the first few sessions of play and keeping a log of gaming time and gaming order. As the monitoring required no specific physiotherapy skills, the level of physiotherapy experience of the research assistants carrying out the intervention on behalf of the researcher was not relevant.

3.7.5 Treatment and measurement

Four children were assessed and treated per school term. Although there is a large body of literature supporting block therapy, there is little information regarding the adequate dosage when aiming to improve postural stability and balance control. Due to ethical considerations related to class absenteeism and disruption of standard physiotherapy routines, it was decided that an intensive intervention program of four sessions a week for three weeks would be more appropriate than a program of two sessions a week for six weeks. Due to the availability of one Wii Fit and the staggered, multiple baseline design, extending the treatment duration to six weeks of therapy, four times a week would have decreased the number of children that could be accommodated in this study from 16 to eight. It was therefore decided that a larger sample number would be favoured over a longer intervention period.

Children were to receive the Wii Fit training instead of their conventional Physiotherapy during the weeks of data collection. The children that had agreed to participate in this study were either receiving individual physiotherapy, group therapy or had plateaued in their motor development and had therefore been discharged from physiotherapy. As a result, it was decided that the Wii Fit training would be given in isolation and instead of conventional therapy to ensure homogeneity of the sample during the Wii Fit training period. All conventional therapy was ceased during Wii Fit training, to diminish the presence conventional therapy as a confounding factor, as conventional therapy during may have masked or enhanced the effect of the Wii Fit training.

The research assistants at each school assigned children to one of two treatment groups: those starting the intervention phase in week three and those starting the intervention phase in week five. Research assistants were asked to assign children to groups randomly, however group assignment was not discussed with the researcher and therefore the process and method of group allocation was not known to her.

University of Cape Town

For some children the intervention schedule had to be altered due to school- and public holidays. One child's treatment had to be extended for an extra week to make up for lost Wii Fit training sessions due to absenteeism. Although treatment onset varied slightly between groups, generally, once three baseline measures of all four children had been taken, two of the children started the intervention. After two weeks, an overlap week was then scheduled where all four children received the intervention. Following the overlap week, the 2nd group continued the intervention for two weeks while the first two children ceased to undergo Wii Fit training. However, these children continued to undergo weekly measurement sessions through to week 9. This ensured that the researcher remained blinded with regards to group assignment.

Table 7: Intervention Schedule

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
Child 1	A	A	A	B 2 PT sessions+ 2 break times	B 2 PT sessions+ 2 break times	B 2 PT sessions+ 1 break time	A	A	A
Child 2	A	A	A	B 2 PT sessions+ 2 break times	B 2 PT sessions+ 2 break times	B 2 PT sessions+ 1 break time	A	A	A
Child 3	A	A	A	A	A	B 2 PT sessions+ 1 break time	B 2 PT sessions+ 2 break times	B 2 PT sessions+ 2 break times	A
Child 4	A	A	A	A	A	B 2 PT sessions+ 1 break time	B 2 PT sessions+ 2 break times	B 2 PT sessions+ 2 break times	A

A = Measurement only
B = Measurement and Intervention

The intervention sessions took place four times a week for 25 minutes at the relevant schools in predetermined time-slots. Children normally undergo an average of two 30 minute sessions of physiotherapy per week. To minimise the time spent outside the classroom, the childrens' regular physiotherapy time slots were used for the intervention as far as possible. Children did not receive their standard physiotherapy treatment during the Wii Fit intervention period. The Nintendo Wii Fit training was used as an alternative

University of Cape Town

form of therapy during these three weeks. An additional half hour was negotiated once a week on a Monday for measurement purposes. This brought the total amount of time spent outside the class room per week to 80 minutes. Each child was asked to offer up two of five weekly break-time slots to prevent further class absenteeism, allowing the four sessions of Wii Fit training time per week. During the overlap week, there were only 5 break- time slots available for use. This meant that each child only received 3 Wii Fit sessions during the overlap week (see Table 7 for details).

Children 1-4 and 5-7 were assessed and treated at School 1 in the 3rd and 4th school terms of 2009 respectively. School physiotherapists acted as research assistants and were responsible for randomising and monitoring gaming activity of the relevant children.

School 2 is a clinical placement for 3rd year physiotherapy students from the University of Cape Town. Physiotherapists at School 2 were unable to assist with this study, therefore 3rd year physiotherapy students on rotation at School 2 acted as research assistants at this school. Children 8-14 were assessed and treated at School 2 in the 1st and 2nd school terms in 2010, overlapping the school holiday. This had to be done since the 3rd year physiotherapy students ended their clinical placement in May 2010.

University of Cape Town

During the Wii Fit gaming sessions, the research assistant would ask the child to remove all shoes, socks and AFOs. It was thought that shoes and AFOs may damage the Wii Fit balance board and wearing socks may cause the child to slip and fall. It was also thought that assistive devices such as AFOs may act as confounding factors. Therefore all children were required to undergo the Wii Fit training and the weekly testing barefoot.

The child was then asked to stand on the Wii Fit balance board while the research assistant operated the gaming controller. Games were divided into categories of antero-posterior, medio-lateral and multidirectional weight shifting. The research assistants were instructed to allow two games per gaming session of ten minutes each but games

had to be rotated to avoid choosing the same game on two consecutive days. A log sheet of gaming order was used to keep track of the child's game choices. This was done to ensure that all categories of weight shifting were challenged in equal proportions. Research assistants were also asked to record the child's gaming score for every game played as well as the child's gaming time, resting time and absenteeism (See Appendix 8.5 for Log sheet). To maintain blinding, the researcher only had access to these log sheets once data collection had been completed for a group.

Seeing as each Wii Fit session lasted for about 20 minutes on average, this allowed for 10 minutes of gaming practise for each of the games chosen. In terms of practice distribution and variability, sessions therefore consisted of massed and constant practice. The practice schedule was blocked because each game was repeated roughly 5 times in 10 minutes before moving on to the second game chosen for a particular session. The child was required to continuously balance and shift weight on the Wii Fit balance board in reaction to the feedback from the television screen, as a result, the nature of the task was complex since movement had to be planned and considered cognitively and specifically to gaming requirements.

In terms of the feedback provided to the child, Wii Fit gaming relies on knowledge of results, as the subject is given feedback about the movement outcome in relation to the goal [18]. If the aim is to head the soccer ball, then the Wii Fit balance board will relay whether or not the child leaned far enough to allow for this to occur. The Wii Fit balance board does not provide information on the actual movement kinematics and movement strategies utilised during a movement trial, as would be the case if feedback were given in the form of knowledge of performance [18]. Feedback is largely immediate as the subject sees whether or not a fish was caught by the penguin or whether or not the bubble was navigated successfully down the river path. The gaming score is only presented at the end of the game though and may therefore be considered as delayed feedback, since the subject only learns of this once the movement trial has been completed. Research assistants were allowed to provide verbal and manual feedback

University of Cape Town

either by speaking to the child during gaming or by placing their hands on the child's pelvis and guiding the child's movement during the first few sessions of Wii Fit gaming. Amount of verbal and manual feedback was not recorded but research assistants commented that children learned fairly quickly and did not require any further verbal or manual assistance beyond the first two Wii Fit sessions.

Research assistants were allowed to instruct the child either by means of verbal commands or hands-on facilitation since children tended to shift their COM rather than their COP in the first few minutes of gaming. Most children understood what was required of them after the first few sessions and facilitation was then no longer required.

Children were allowed to take bathroom breaks or drink water during the intervention and fatigue was considered within reason. Research assistants were instructed to allow rest periods limited to 5 minutes in total if necessary, in order to maintain the length of the treatment sessions. Children were not required to concentrate for 20 minutes solidly as the Nintendo Wii Fit games take 2 minutes to complete after which the player is allowed a rest period of roughly 20 seconds while resetting the game.

Every Monday, the researcher would visit the school in question and would assess children who were to undergo the intervention in that particular school term. Each measurement session took roughly half an hour to complete. Adequate time slots were negotiated with the child's teacher to ensure that measurement sessions did not encroach on the child's academic work. Children and research assistants at the relevant schools were informed that the researcher was to remain blinded to group assignment. The researcher was therefore unaware when children had undergone treatment throughout the nine week period of measurement.

For the baseline measurement, the researcher assessed each child's ankle and knee joint range with a goniometer as well as their level of Quadriceps, Hamstring and Triceps

University of Cape Town

surae spasticity according to the Modified Ashworth Scale. All children completed the adapted Subtests 5 and 6 of the BOT-2, the TUDS test and the EQ-5D-Y every week during their measurement session. Testing was undertaken in a quiet room that was close to a corridor, where the shuttle-run of Subtest 6 and the TUDS test could be completed. The researcher used masking tape to indicate the straight line required for Subtest 5 as well as the 15 meter shuttle run-way required for Subtest 6. The visual target for Subtest 5 was mounted on a wall and the child was required to stand 2 meters away from the wall during the balance tests. Children were asked to remove their shoes socks and AFOs for testing. Time was kept with a stop watch and scores were recorded on assessment sheets.

In the measurement periods before and after the Nintendo Wii Fit intervention phase, children continued with their usual physiotherapy schedules.

Eight weeks after intervention cessation, a two month post-intervention measurement was taken to investigate whether possible improvements on the outcome measures had been retained. The final measurement session was undertaken on the 24th of July 2010 effectively ending data collection on that day.

University of Cape Town

3.7.6 Data management

Consent forms, assessment forms and EQ-5D-Y self-reports were kept in individual folders for every child. Folders were numbered to maintain anonymity. The data was entered into Excel spreadsheets every week following measurement. The STATISTICA 8 [241] and NCSS [242] software programs were used for data analysis. NCSS was used for the ROC analyses while STATISTICA 8 was used for all other analyses.

3.8 Statistical analysis

The first baseline measure was taken on a Monday on the first contact with the child. From then on each week was considered to run from Tuesday to Monday meaning that the 2nd measure was then at the end of the first week and was called Week 1. Each week therefore ended with assessment on a Monday. This meant that the intervention phase data were collected after the first week of intervention and not at the start of the week. In these tables, the baseline phase is indicated by an **ni** (no intervention) and the intervention phase is indicated by an ***i*** *(intervention).* The highest achievable converted score for the adapted BOT-2 Subtest 5: Balance was 52 total pointscore while the highest achievable converted score for the adapted BOT-2 Subtest 6: Running Speed and Agility was 72 total pointscore. The TUDS test was measured in seconds with a stop watch. The EQ-5D-Y VAS was measured on a scale from 0 – 100.

Line graphs of each child's Balance, Running Speed and Agility and TUDS scores were created to allow for comparison of the child's motor performance during the baseline and intervention phase. The VAS was not graphed as there was little variance and the range of possible pointscores (0-100) was much larger than those of the other scales. On the line graphs, it was desirable for the Balance and Running Speed/Agility scores to show a positive or increasing trend since an increase in scores indicates an improvement in balance and running speed/agility. For the TUDS scores it was desirable to see a decreasing or negative trend since a decrease in TUDS scores indicates decreased time to completion of the TUDS test meaning that the child is negotiating the stairs faster.

On the graphs, the intervention phase was indicated by two vertical lines for ease of reference. As noted above, since weekly measurements were taken on the first day of the week, the first data point during the intervention phase was counted as a baseline score since the child had not received any Wii Fit treatment. The first data point at the beginning of the second week of intervention was then seen as the first real intervention phase data point since the child would have undergone one week of intervention by then.

University of Cape Town

Statistical analysis was used to investigate whether treatment had made a difference to the outcome measures. Owing to the small number of participants available, parametric comparison of pre- and post- test results was likely to be underpowered. As a result statistical methods used in single-subject research designs were employed. The ROC analysis function was utilised to investigate treatment effectiveness. Area under the curve outputs were used to establish the degree of Non-overlap of all Pairs (NAP), as discussed under section 2.7. Post-intervention measures were necessary to ensure the researcher remained blinded while completing measurement of all children up to week nine. These measures were not included in the ROC analysis.

The ROC analysis procedure is as follows: baseline phase data is coded as 0 and intervention phase data is coded as 1. The baseline and intervention phase data are then entered vertically in the same column. Upon selecting the ROC curve analysis, the data point column is selected as the test variable and the corresponding coded column is selected as the classification variable. The NAP index can then be read from the AUC column in the output table. Recommended ranges for effect size interpretation are 0.50 - 0.65 for a small treatment effect, 0.66 - 0.92 for a medium treatment effect and 0.93 - 1.00 for a large treatment effect. Where a decreasing trend indicates an improvement, these ranges are inverted to 0.50 – 0.35 for a small, 0.34 – 0.08 for a medium and 0.07 – 0.00 for a large treatment effect. The confidence intervals that would ordinarily accompany the AUC indicate the level of significance. If the CIs do not overlap 0.5, then data points in the baseline and intervention phases are significantly different. For example, for the Balance score the ideal AUC would fall between 0.93 – 1 with a CI that does not overlap 0.5. This would indicate a large treatment effect as well as a significant improvement in balance. However, upon data analysis in NCSS, results were accompanied with a footnote saying that the program underestimates the AUC when there are fewer than 7 unique criterion values. This was the case in some of the analyses. As a result the confidence intervals were very wide. This limitation had not been anticipated before data collection and therefore it was decided that confidence intervals could not be relied on for data interpretation. Only the AUC was reported along with the Standard Error and the effect size. This was the primary analysis. As the CIs were not

University of Cape Town

included in the analysis, further statistical testing of whether improvement had taken place was undertaken.

The only analysis that was done on the post-intervention measures was between the last baseline, the last intervention phase and the two month post intervention measures in order to establish whether any improvements in outcome measures had been retained over a 2 month period. A Friedman's ANOVA and post-hoc analysis were used for this purpose.

A Chi-Square analysis was done to determine whether the demographic or medical variables had an influence on the effect size of the Balance, Running Speed and Agility and TUDS scores. Only cross-tabulations that demonstrated a significant association are presented in the Results section. The remaining output tables of interest can be found in Appendix 8.6.

Spearman's Rank Order correlations were used to establish whether Wii Fit training time and Wii Fit gaming score were associated with performance on the outcome measures.

A Wilcoxon matched pairs test was done to establish whether a change was seen in the gaming scores from the first to the last training session.

3.9 Ethical considerations

3.9.1 Beneficence

Children at the relevant special needs schools receive physiotherapy treatment twice a week for 30 minutes on average, however, many of the children who were included in this study normally undergo group physiotherapy sessions. Although children received

University of Cape Town

only the Nintendo Wii Fit training instead of their standard physiotherapy during the three week intervention phase, participation meant that children completed the Nintendo Wii Fit training individually and for four sessions a week instead of having group therapy twice a week. Based on the literature and the scientific rationale for the intervention, it was anticipated that participation in this study might benefit children in their motor development.

Previous trials when testing the feasibility of this study showed that the hemiplegic children enjoyed the Nintendo Wii Fit games tremendously. The variation in exercise routine over the three week intervention period was welcomed by most of the children who participated in this study.

Participants did not receive any form of payment for their participation in this study but as a token of appreciation, children were given a small assortment of sweets once they had completed their 9th measurement session.

University of Cape Town

3.9.2 Nonmaleficence

The fact that children spent more time outside the classroom than usual, might have been a legitimate cause for concern as this may have caused children to fall behind in their school work. However, children were only outside the classroom for an extra 30 minutes per week over a period of nine weeks for measurement purposes. These time slots were negotiated with the child's teacher while taking the child's time-table into account. Children did not miss any important assessments or tests for the purpose of intervention or measurement. No additional time outside of normal school hours was requested for the purpose of this study.

Another cause for concern may have been that children participating in this study had to refrain from their standard physiotherapy treatment for a period of three weeks while

undergoing the Nintendo Wii Fit intervention. In discussions with school physiotherapists, it was concluded that children would only miss out on six of their standard physiotherapy sessions and that this is less than children might miss out on during a mid-year holiday for example. In addition to this, children received the Nintendo Wii Fit as an alternative form of exercise and therefore were still considered to be physically active during the intervention phase. As a result, the researcher believes that children were not disadvantaged by a three week break in their normal physiotherapy routine.

Children were allowed to take bathroom breaks or drink water during the intervention. Fatigue was considered within reason. Physiotherapists were instructed to allow rest periods limited to a maximum of 5 minutes in order to maintain the length of treatment sessions. Generally, the Nintendo Wii Fit games take 2 minutes to complete after which the player is allowed a rest period of roughly 20 seconds while resetting the game. Children were therefore not required to concentrate solidly for 20 minutes.

Video games are known to trigger seizures or black outs in people suffering from epilepsy [243-245]. The information leaflet included a section that requested parents to decline participation in this study if their child was epileptic. None of the parents reported epilepsy in their children. The school physiotherapists were also consulted to ensure that children who suffer from seizures or epileptic attacks were excluded from this study.

Delayed onset muscle soreness or muscle ache is a common consequence of unaccustomed exercise. Although muscle activation of previously inactive muscles is likely when starting the Nintendo Wii Fit, children were not expected to experience serious discomfort as a result of this. If the use of the Nintendo Wii Fit had lead to pain and discomfort of any kind, then the child's participation in this study would have been discontinued.

University of Cape Town

The Nintendo Wii Fit is 5 cm in height. This means that children had to balance on a surface that is slightly raised above the ground. Although falls and serious injury were unlikely, physiotherapists who monitor the gaming sessions were asked to remain alert and prevent falls where possible. Physiotherapists were also instructed to clear the area around the balance board to prevent serious injury should a fall occur. Children who participated in this study were covered by the UCT Group Insurance plan and would have been compensated in the unlikely event of any study related injury, should one have occurred.

3.9.3 Autonomy

Prior to the data collection period, parents/ legal guardians and children were given information leaflets and consent forms. The information leaflets gave guardians insight into the purpose of this study. Parents and children were equally entitled to decline participation in this study. The decision of a parent or child to discontinue the study would have been respected without question. This was clearly stated on the Information leaflet received by parents and guardians (See Appendices 8.2 and 8.3 for information leaflets and consent forms).

University of Cape Town

Children were given a say in the intervention since they were allowed to choose the balance game that they wanted to play during each treatment session. The series of tests in the outcome measures however were not negotiable and children had to undergo this uniform battery of tests required to monitor their progress every Monday for 9 consecutive weeks.

3.9.4 Confidentiality

The data collected in this study are confidential. All children were assigned a number for identification purposes. The name of the child was not be used in conjunction with any

data or test scores thereby ensuring anonymity of all children. Only the researcher had access to the child's personal information.

3.9.5 Declaration of Helsinki

This study adhered to the ethical principles for medical research involving human subjects as stipulated by the World Medical Association Declaration of Helsinki version 2000 [246].

University of Cape Town

University of Cape Town

University of Cape Town

4. Results

The demographic characteristics of the participants are presented first. For each child, tables of the outcome measure scores are shown. These tables contain the baseline and intervention phase measures that were taken over a period of 9 weeks.

4.1 Participant characteristics

4.1.1 Demographic details

A total of 14 participants were included in this study. This sample consisted of eight boys and six girls. The mean age was 11.36 years (SD = 1.82), the youngest child being seven years old and the oldest child being 14 years old. Academic achievement was divided into two categories: Satisfactory and Unsatisfactory. These terms refer to the child's academic achievement for their age and were stated as such in each child's academic school folder that the researcher was given access to at the relevant schools. This information was included since it was thought that academic achievement may be a reflection of the child's cognitive ability, which may have influenced the child's ability to engage in Wii Fit gaming. Five of the 14 children demonstrated unsatisfactory academic performance for their age and grade (one of these children was medicated for ADHD while the remaining four had a learning disorder). Four of the older and more functional children had been discharged from physiotherapy and were not receiving any form of therapy at the time of data collection.

University of Cape Town

Table 8: Child 1-14 Demographic and Academic information

Child	Gender	Age	Grade	Academic achievement	Therapy
Child 1	Male	13	6	Satisfactory	No
Child 2	Male	10	4	Satisfactory	Yes
Child 3	Female	14	5	Satisfactory	No
Child 4	Female	11	6	Satisfactory	Yes
Child 5	Male	9	2	Satisfactory	Yes
Child 6	Male	12	3	Satisfactory	Yes
Child 7	Female	11	3	Unsatisfactory	Yes
Child 8	Male	13	4	Unsatisfactory	Yes
Child 9	Male	7	1	Unsatisfactory	Yes
Child 10	Female	11	4	Satisfactory	Yes
Child 11	Female	11	5	Unsatisfactory	No
Child 12	Male	13	6	Satisfactory	No
Child 13	Female	12	5	Satisfactory	Yes
Child 14	Male	12	5	Unsatisfactory	Yes

***Age and Grade refer to those at time of treatment**

4.1.2 Medical History

Of the 14 participants, seven had a left-sided hemiplegia and seven had a right-sided hemiplegia. Nine children had a congenital hemiplegia. The remaining five had all acquired cerebral palsy post-natally. Three children were required to wear an AFO on a daily basis at the time of data collection. Three children had previously worn an AFO but were no longer required to do so. The remaining eight children had never worn an AFO. Twelve of the children had undergone surgery or medical interventions such as Botox or tendon lengthening procedures. Two of the children were on Ritalin while the remaining twelve were not receiving any medication at the time of data collection. Five of the 14 children were classified at Level I while nine were classified at Level II on the GMFCS.

University of Cape Town

Table 9: Child 1-14 Medical Information

Child	Side of Hemiplegia	Acquired / Congenital	AFO	Previous Surgery	Meds	GMFCS Level
Child 1	L	C	No	Yes	None	1
Child 2	L	C	Yes	Yes	Ritalin	2
Child 3	L	C	No longer	Yes	None	2
Child 4	L	C	No	Yes	None	1
Child 5	L	C	Yes	Yes	None	2
Child 6	R	A	No	Yes	None	2
Child 7	L	A	Yes	Yes	None	2
Child 8	L	A	No	Yes	None	2
Child 9	R	A	No	No	Ritalin	1
Child 10	R	C	No longer	Yes	None	2
Child 11	R	C	No	No	None	1
Child 12	R	C	No	Yes	None	1
Child 13	R	A	No longer	Yes	None	2
Child 14	R	C	No	Yes	None	2

University of Cape Town

4.1.3 MAS measures

Only three of the 14 children were found to have full range of motion at the knee and ankle. The other 11 all had a plantarflexion contracture, a knee flexion contracture or both. Of the three muscle groups assessed, the Triceps Surae muscle group was the most affected with regards to hypertonia.

Table 10: Child 1-14 MAS scores and Joint contractures

Child	MAS Tr. S.	MAS Hamstr.	MAS Quadr.	Ankle plantarflexion contracture *	Knee flexion contracture *
Child 1	1	1	0	8 degrees short of plantargrade	14 degrees short of extension
Child 2	1	1	0	10 degrees short of plantargrade	Full Range of Motion
Child 3	1	1	0	Full Range of Motion	Full Range of Motion
Child 4	0	1	1	Full Range of Motion	Full Range of Motion
Child 5	2	1	1	11 degrees short of plantargrade	11 degrees short of knee flexion
Child 6	2	1	1	6 degrees short of plantargrade	Full Range of Motion
Child 7	2	1	1	7 degrees short of plantargrade	3 degrees short of extension
Child 8	2	0	0	10 degrees short of plantargrade	Full Range of Motion
Child 9	1	0	0	plantargrade - no dorsiflexion range	Full Range of Motion
Child 10	1	1	0	plantargrade - no dorsiflexion range	10 degrees short of extension
Child 11	1	0	0	Full Range of Motion	Full Range of Motion
Child 12	1	1	0	plantargrade - no dorsiflexion range	Full Range of Motion
Child 13	1	1	1	10 degrees short of plantargrade	Full Range of Motion
Child 14	1	1	0	5 degrees short of plantargrade	Full Range of Motion

MAS = Modified Ashworth Scale
Tr. S. = Triceps Surae
Hamstr. = Hamstrings
Quadr. = Quadriceps
*** Intra-observer measurements have been shown to demonstrate mean measurement errors of 5 degrees (SD 5 degrees), therefore an average of 3 readings was recorded.**

University of Cape Town

4.2 Wii fit training results

4.2.1 Wii Training Time

Each child's Wii Fit training time was recorded over the 3 week intervention period. Some children were absent due to illness or religious holidays. The total Wii Fit training time is presented in the table below.

Table 11: Total Wii Fit training time

Child	Wii Fit time in min	Wii Fit time in hrs	Remarks
Child 1	243	4 hrs 3 min	
Child 2	228	3 hrs 48 min	
Child 3	236	3 hrs 56 min	
Child 4	247	4 hrs 7 min	
Child 5	289	4 hrs 49 minutes	Absent one day
Child 6	170	2 hrs 50 minutes	Absent three days
Child 7	225	3 hrs 45 minutes	Absent two days
Child 8	223	3 hrs 43 min	
Child 9	209	3 hrs 29 min	
Child 10	215	3 hrs 33 min	
Child 11	189	3 hrs 9 min	
Child 12	175	2 hrs 55 min	Absent three days
Child 13	208	3 hrs 28 min	
Child 14	191	3 hrs 11 min	Absent one day

Mean Wii Fit training time was 217.71 minutes with a standard deviation of 31.52 minutes.

University of Cape Town

4.2.2 Individual Results

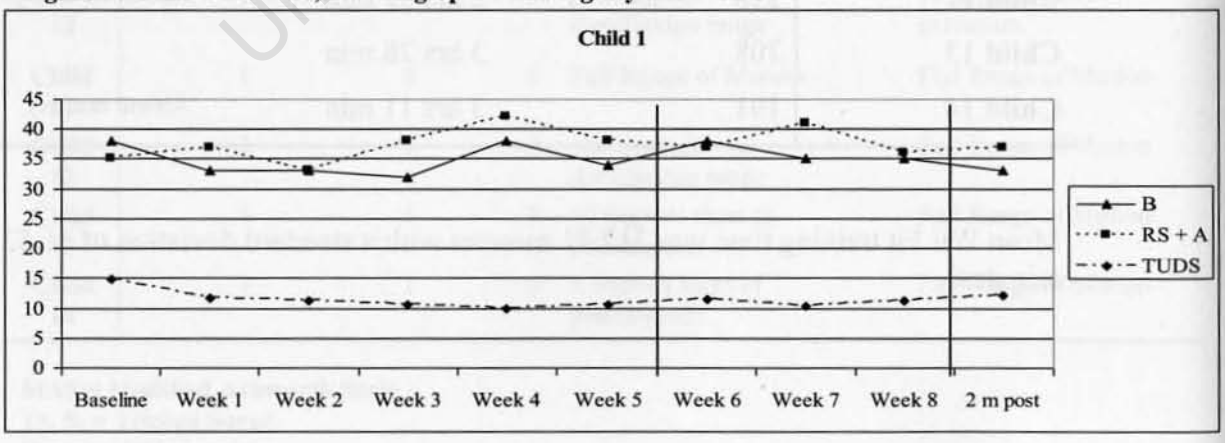
Child 1

Child 1 was a 13 year old male. He was in grade 6 and showed satisfactory academic achievement. He had a left-sided hemiplegia and was classified at Level I on the GMFCS. He was given an MAS score of 1 for the Triceps surae and Hamstring muscle groups. Child 1 had an ankle plantarflexion contracture of eight degrees and a knee flexion contracture of 14 degrees. He did not wear an AFO but did have previous surgery on his lower limb. Child 1 underwent the intervention in weeks 6-8.

Table 12: Child 1 Balance, Running Speed and Agility TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	b	ni	ni	ni	ni	ni	*i*	*i*	*i*	p
Balance	38	33	33	32	38	34	*38*	*35*	*35*	33
RS and A	35	37	33	38	42	38	*37*	*41*	*36*	37
TUDS	14.9	11.63	11.3	10.64	10	10.47	*11.5*	*10.29*	*11.19*	12.04
VAS	100	95	100	100	100	100	*100*	*100*	*100*	100

Figure 4: Child 1 Balance, Running Speed and Agility and TUDS



University of Cape Town

Table 13: Child 1 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect size
Balance	0.72	0.18	Medium improvement
RS + A	0.53	0.23	Small improvement
TUDS	0.44	0.22	Small improvement
VAS	0.58	0.22	Small improvement

The line graph for Child 1 does not suggest important improvements in any of the outcome measures. The ROC curve output table shows that Child 1 had an increasing trend in Balance scores leading to a medium improvement in balance. Only small improvements were seen on the other outcome measures.

University of Cape Town

Child 2

Child 2 was a 10 year old male in grade 4 with satisfactory academic achievement. He had a left-sided hemiplegia and was classified at Level II on the GMFCS. He was given an MAS score of 1 for the Triceps surae and Hamstring muscle groups and had an ankle plantarflexion contracture of 10 degrees. Child 2 was required to wear an AFO and was receiving Ritalin at the time of data collection. He had previously received surgery to his upper limb. Child 2 underwent the intervention in weeks 4-6.

Table 14: Child 2 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	ni	ni	ni	ni	*i*	*i*	*i*	ni	ni	p
Balance	28	23	27	32	*28*	*35*	*36*	28	27	29
RS and A	29	25	30	31	*25*	*27*	*30*	22	26	26
TUDS	19.88	13.47	15.8	14.54	*12.26*	*13.27*	*16.76*	14.21	11.91	15.79
VAS	100	100	99	100	*95*	*100*	*100*	97	100	100

Figure 5: Child 2 Balance Running Speed and Agility and TUDS

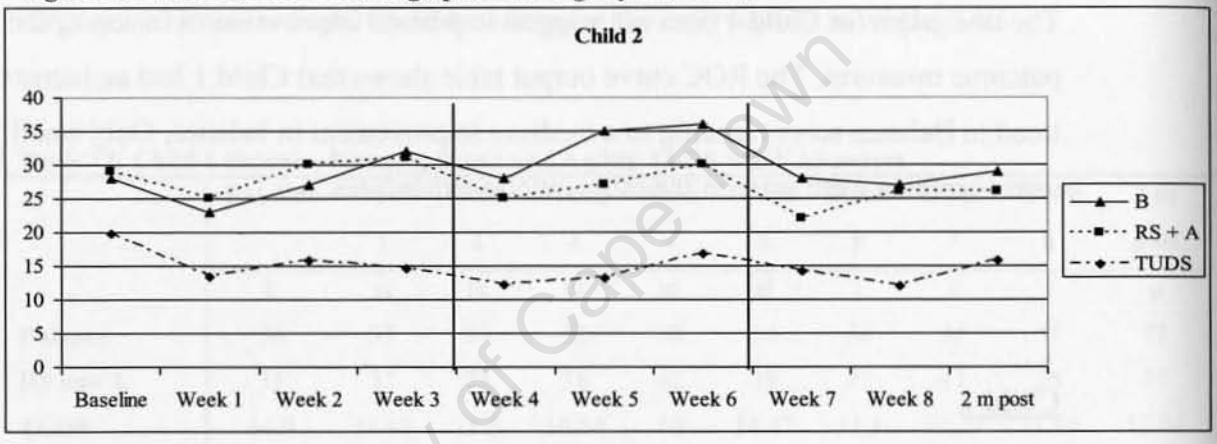


Table 15: Child 2 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	0.88	0.15	Medium improvement
RS + A	0.33	0.23	Medium deterioration
TUDS	0.25	0.26	Medium improvement
VAS	0.42	0.22	Small deterioration

Visual analysis of the graph, reveals that the Balance score started rising slightly in the baseline phase before the onset of intervention. However, a more marked increase is visible during the intervention. The AUC indicates a medium improvement for the

University of Cape Town

Balance and TUDS scores. The Running Speed and Agility and VAS scores were seen to deteriorate over time.

Child 3

Child 3 was a 14 year old female and the oldest participant in the study sample. She was in grade 5 and had satisfactory academic achievement. She had a left hemiplegia and had previously worn an AFO but was no longer required to do so at the time of data collection. She was awarded an MAS score of 1 for the Triceps surae and Hamstring musclce groups but had full range of motion at the ankle and knee. She had also had multiple previous surgeries to her lower limb. Child 3 underwent the intervention in weeks 6-8.

University of Cape Town

Table 16: Child 3 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	ni	ni	ni	ni	ni	ni	*i*	*i*	*i*	p
Balance	37	32	28	34	32	35	*33*	*31*	*38*	35
RS and A	29	36	30	36	28	32	*32*	*36*	*35*	29
TUDS	11.53	11.44	11.45	11.53	10.41	11.44	*11.55*	*10.68*	*10.69*	12.72
VAS	100	95	95	85	75	100	*95*	*100*	*100*	99

Figure 6: Child 3 Balance, Running Speed and Agility and TUDS

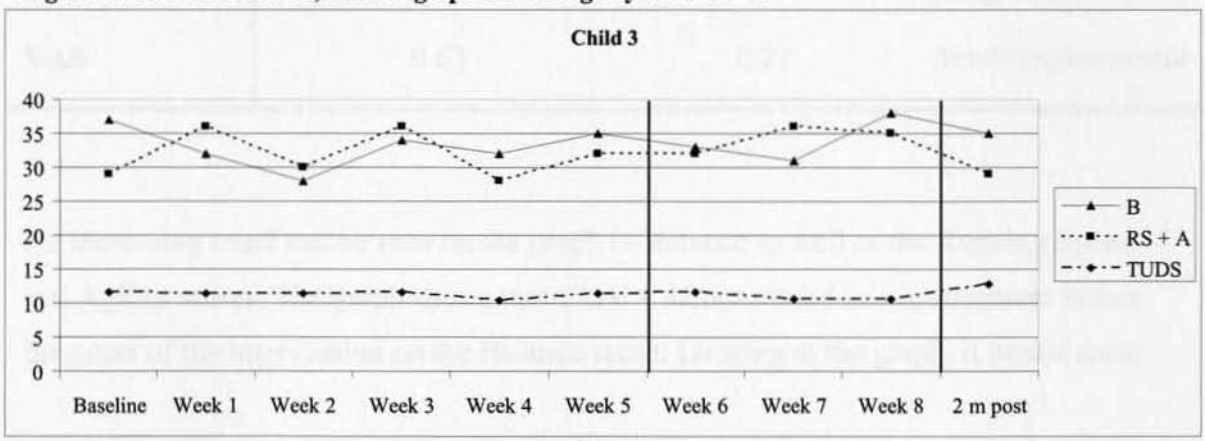


Table 17: Child 3 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	0.56	0.27	Small improvement
RS + A	0.69	0.18	Medium improvement
TUDS	0.44	0.30	Small improvement
VAS	0.72	0.16851	Medium improvement

After an initial negative trend, Child 3's graph shows a slight positive trend in Balance scores. However, only small to medium improvements were seen on the outcome measures between the baseline and intervention phases.

University of Cape Town

Child 4

Child 4 was an 11 year old female in grade 6 with satisfactory academic achievement. She had a left-sided hemiplegia with the upper limb being more affected than the lower limb. As a result, she was classified at Level I on the GMFCS. She was awarded an MAS score of 1 for the Quadriceps and Hamstring muscle groups but had full range of motion at the ankle and knee. She was not required to wear an AFO but was required to wear a hand splint. She had had previous surgery on her upper and lower limb. Child 4 underwent the intervention in weeks 4-6.

Table 18: Child 4 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	b	ni	ni	ni	*i*	*i*	*i*	ni	ni	p
Balance	35	44	42	48	*46*	*50*	*49*	47	49	48
RS and A	33	36	36	35	*39*	*45*	*45*	43	46	44
TUDS	10.09	9.57	10.33	9.37	*9.13*	*9.32*	*9.33*	9.48	9.19	9.54
VAS	95	100	85	100	*95*	*100*	*100*	100	100	100

Figure 7: Child 4 Balance, Running Speed and Agility and TUDS

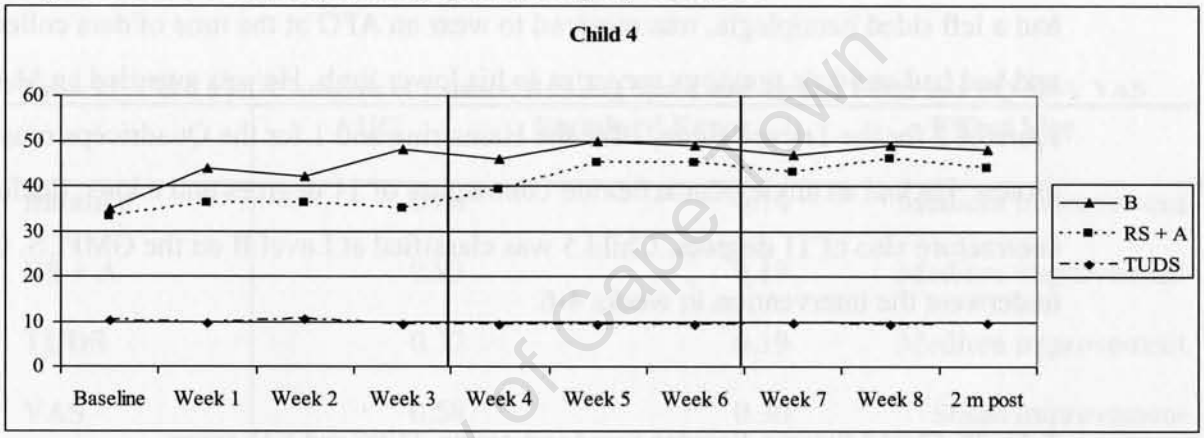


Table 19: Child 4 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	0.92	0.12	Medium improvement
RS + A	1.00		Large improvement
TUDS	0.00		Large improvement
VAS	0.63	0.21	Small improvement

An increasing trend can be seen on the graph in Balance as well as the Running Speed and Agility scores. The graph shows that Child 4 demonstrated an improvement before the onset of the intervention on the Balance score. Looking at the graph, it would seem

University of Cape Town

as though Child 4 did not show a notable decrease in TUDS score, however, upon closer inspection of the raw data, it was found that none of the scores in the baseline phase overlapped with the scores in the intervention phase. Therefore the ROC analysis shows a large treatment effect for the TUDS as well as the Running Speed and Agility score.

Child 5

Child 5 was a nine year old male in grade 2 with satisfactory academic achievement. He had a left sided hemiplegia, was required to wear an AFO at the time of data collection and had had multiple previous surgeries to his lower limb. He was awarded an MAS score of 2 for the Triceps surae, 1 for the Hamstring and 1 for the Quadriceps muscle groups. He had an ankle plantarflexion contracture of 11 degrees and a knee flexion contracture also of 11 degrees. Child 5 was classified at Level II on the GMFCS. Child 5 underwent the intervention in weeks 4-6.

University of Cape Town

Table 20: Child 5 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**2 m post**
	b	ni	ni	ni	*i*	*i*	*i*	ni	ni	p
Balance	41	37	33	36	*41*	*38*	*44*	38	42	40
RS and A	27	30	30	25	*29*	*31*	*31*	29	28	32
TUDS	20.32	19.11	23.27	25.87	*23.4*	*24.23*	*24.53*	25.99	23.4	22.85
VAS	100	99	99	82	*75*	*100*	*100*	100	100	100

Figure 8: Child 5 Balance, Running Speed and Agility and TUDS scores

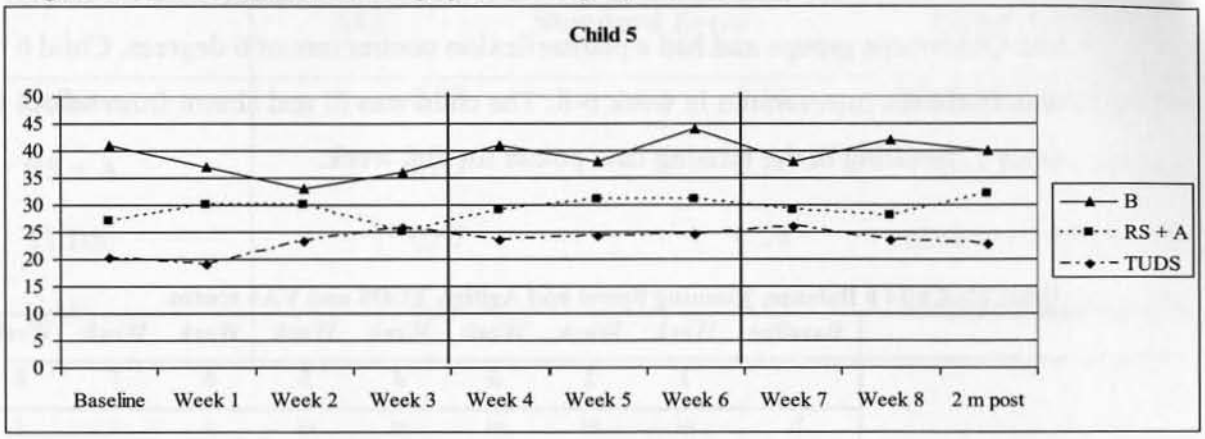


Table 21: Child 5 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	0.88	0.14	Medium improvement
RS + A	0.83	0.19	Medium improvement
TUDS	0.17	0.19	Medium improvement
VAS	0.58	0.30	Small improvement

University of Cape Town

After an initial decreasing trend, Child 5's graph shows an increasing trend in Balance score that correlates well with the onset of the intervention. The ROC output table however only demonstrates a medium treatment effect for the Balance, Running Speed and Agility and TUDS measures.

Child 6

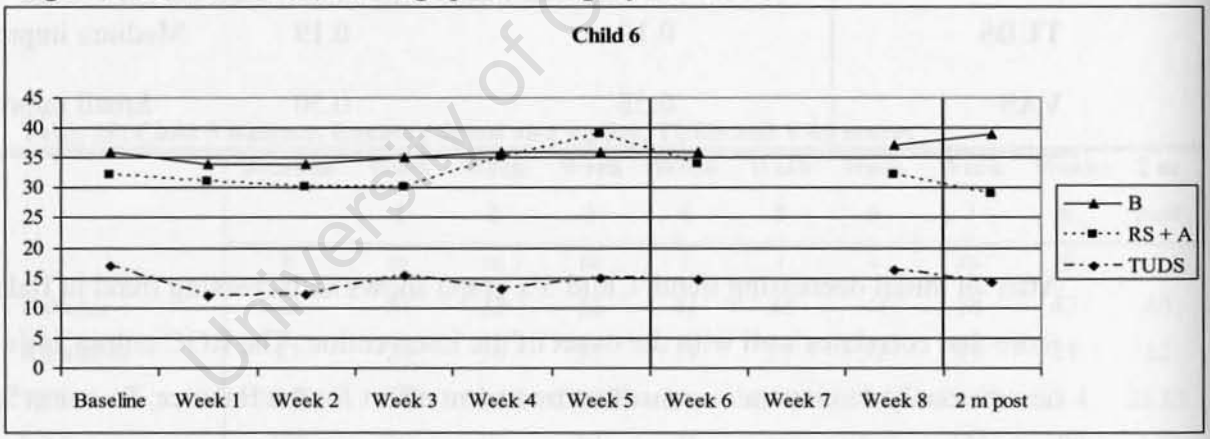
Child 6 was a 12 year old male in grade 3 with satisfactory academic achievement. He had a right-sided hemiplegia. Child 6 was not required to wear an AFO but he was required to wear a hand splint. He had also had previous surgery to his upper and lower

limb. He was awarded MAS scores of 2 for the Triceps surae and 1 for the Hamstring and Quadriceps groups and had a plantarflexion contracture of 6 degrees. Child 6 underwent the intervention in week 6-8. The child was ill and absent from school in week 7, resulting in the missing data points for that week.

Table 22: Child 6 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	b	ni	ni	ni	ni	ni	*i*	*i*	*i*	p
Balance	36	34	34	35	36	36	*36*		*37*	39
RS and A	32	31	30	30	35	39	*34*		*32*	29
TUDS	17.01	12.04	12.19	15.39	13.12	14.87	*14.6*		*16.35*	14.21
VAS	75	95	50	100	15	25	*100*		*95*	50

Figure 9: Child 6 Balance, Running Speed and Agility and TUDS



University of Cape Town

Table 23: Child 6 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	0.88	0.14	Medium improvement
RS + A	0.63	0.21	Small improvement
TUDS	0.67	0.24	Medium deterioration
VAS	0.83	0.15	Medium improvement

The Balance as well as the Running Speed and Agility scores show a trend towards improvement on the graph prior to intervention. Only medium treatment effects were seen on the Balance and VAS scores. The TUDS shows a deteriorating trend. Child 6 complained of a toothache in week two, discomfort in his arm in week three and a stomach ache in week five. He was however happy to continue with testing when given the choice. In week seven, Child 6 missed four Wii Fit training sessions as well as a measurement session.

University of Cape Town

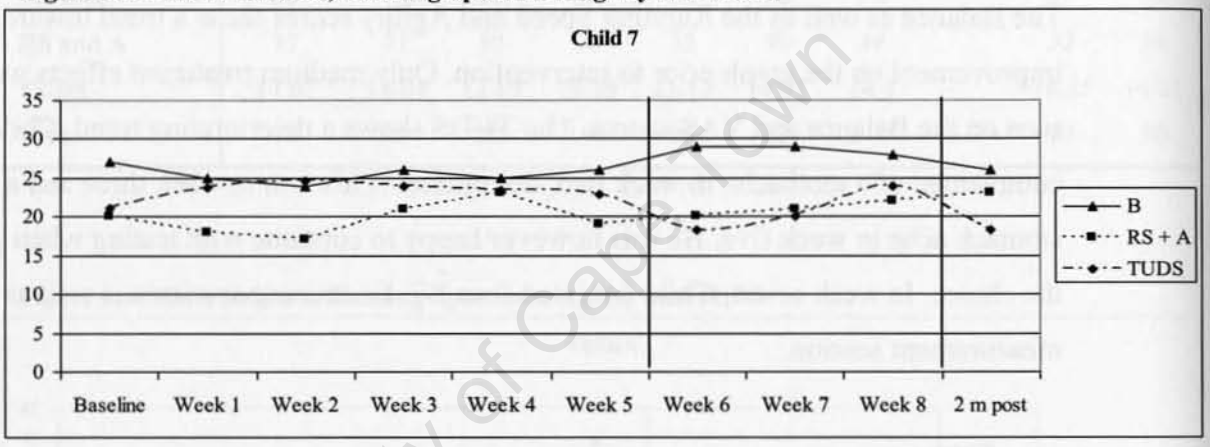
Child 7

Child 7 was an 11 year old female in grade 3 with unsatisfactory academic performance. She had a left-sided hemiplegia and was classified at Level II on the GMFCS. She was awarded MAS scores of 2 for the Triceps surae, 1 for the Hamstring and 1 for the Quadriceps muscle groups. She had a plantarflexion contracture of 7 degrees and a knee flexion contracture of 3 degrees. At the time of data collection she was required to wear a hand splint and an AFO. She had also had previous surgeries to the upper and lower limb. Child 7 underwent the intervention in weeks 6-8.

Table 24: Child 7 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	b	ni	ni	ni	ni	ni	*i*	*i*	*i*	p
Balance	27	25	24	26	25	26	*29*	*29*	*28*	26
RS and A	20	18	17	21	23	19	*20*	*21*	*22*	23
TUDS	21.14	23.74	24.58	23.91	23.41	22.79	*18.32*	*20.07*	*23.9*	18.29
VAS	100	50	90	100	100	100	*100*	*100*	*100*	100

Figure 10: Child 7 Balance, Running Speed and Agility and TUDS



University of Cape Town

Table 25: Child 7 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	95% CI
Balance	1.00		Large improvement
RS + A	0.72	0.18	Medium improvement
TUDS	0.22	0.23	Medium improvement
VAS	0.67	0.11	Medium improvement

Child 7 demonstrated a large treatment effect from the baseline to the intervention phase for the Balance score. This improvement can clearly be seen to have taken place during

the intervention phase. The same trend is seen in the TUDS score, however the AUC only indicates a medium treatment effect for this score.

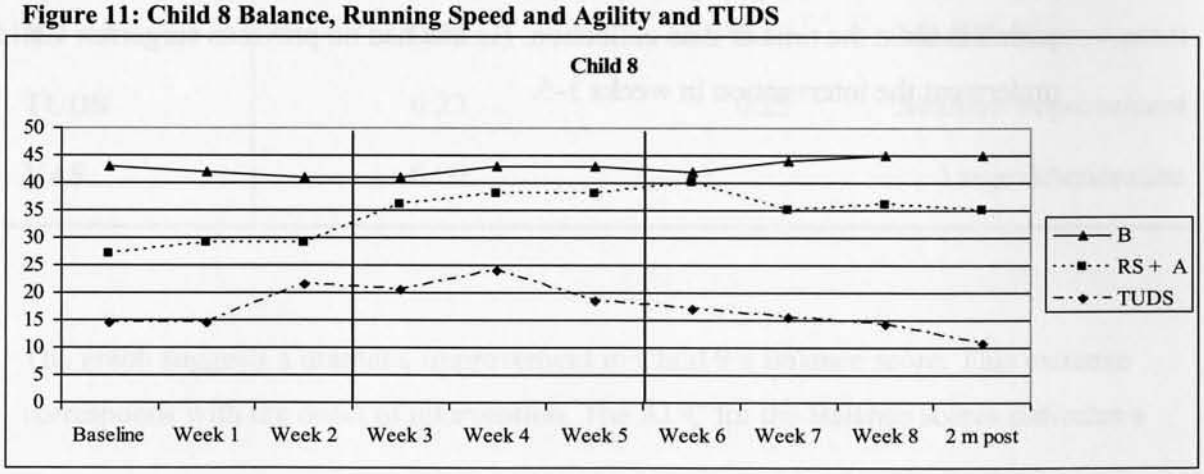
Child 8

Child 8 was a 13 year old male in grade 4 with unsatisfactory academic performance. He had a left-sided hemiplegia and was classified at Level II on the GMFCS. He was awarded an MAS score of 2 for the Triceps surae group and had an ankle plantarflexion contracture of 10 degrees. He was not required to wear an AFO at the time of data collection but had had previous surgery to the upper and lower limb. Child 8 underwent the intervention in weeks 3 to 5.

Table 26: Child 8 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	b	ni	ni	*i*	*i*	*i*	ni	ni	ni	p
Balance	43	42	41	*41*	*43*	*43*	42	44	45	45
RS and A	27	29	29	*36*	*38*	*38*	40	35	36	35
TUDS	14.62	14.51	21.46	*20.62*	*23.91*	*18.38*	17	15.58	14.37	10.79
VAS	55	65	75	*55*	*55*	*50*	30	50	55	70

Figure 11: Child 8 Balance, Running Speed and Agility and TUDS



University of Cape Town

Table 27: Child 8 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	95% CI
Balance	0.61	0.27	Small improvement
RS + A	1.00		Large improvement
TUDS	0.78	0.25	Medium deterioration
VAS	0.11	0.12	Medium deterioration

The graph demonstrates an increasing trend in Running Speed and Agility score during the intervention phase. The AUC indicates a large treatment effect from the baseline to the intervention phase. Both the TUDS and VAS scores demonstrate deterioration over time.

University of Cape Town

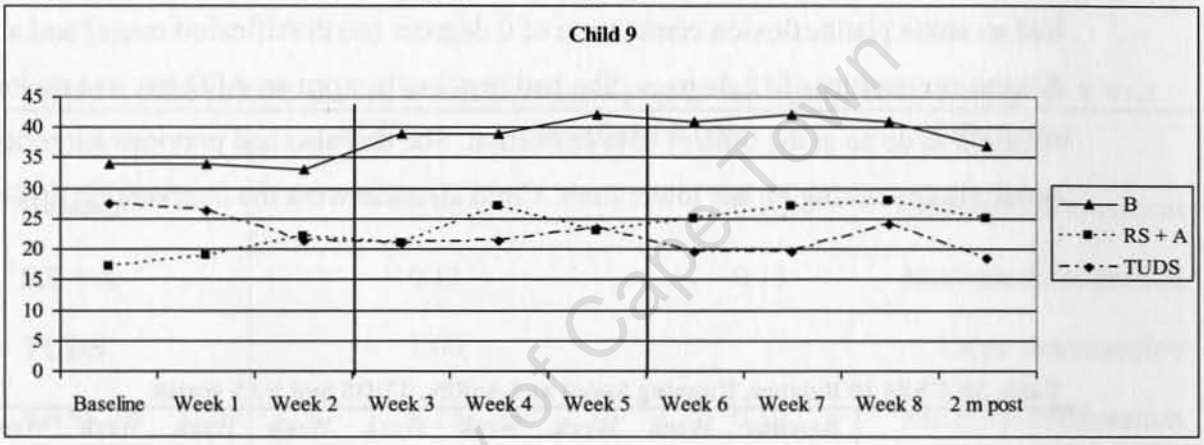
Child 9

Child 9 was a seven year old male in grade 1 and therefore the youngest in the study sample. He demonstrated unsatisfactory academic performance. Child 9 had a right-sided hemiplegia and was classified at Level I on the GMFCS. He was awarded an MAS score of 1 for the Triceps surae muscle group and had a plantarflexion contracture of 0 degrees (no dorsiflexion range). He was not required to wear an AFO but was medicated with Ritalin at the time of data collection. He had had no previous surgeries. Child 9 underwent the intervention in weeks 3-5.

Table 28: Child 9 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	b	ni	ni	*i*	*i*	*i*	ni	ni	ni	p
Balance	34	34	33	*39*	*39*	*42*	41	42	41	37
RS and A	17	19	22	*21*	*27*	*23*	25	27	28	25
TUDS	27.42	26.37	21.3	*20.83*	*21.41*	*23.42*	19.64	19.56	24.01	18.42
VAS	100	100	100	*90*	*50*	*95*	50	100	100	100

Figure 12: Child 9 Balance, Running Speed and Agility and TUDS



University of Cape Town

Table 29: Child 9 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	1.00		Large improvement
RS + A	0.89	0.16	Medium improvement
TUDS	0.22	0.25	Medium improvement
VAS	0.00		Large deterioration

The graph suggests a dramatic improvement in Child 9's Balance score. This increase corresponds with the onset of intervention. The AUC for the Balance scores indicates a

large treatment effect. The Running Speed and Agility and TUDS scores indicate a medium treatment effect. The VAS shows a large deterioration over time.

Child 10

Child 10 was an 11 year old female in grade 4 with satisfactory academic achievement. She had a right-sided hemiplegia and was classified at Level II on the GMFCS. She was awarded an MAS score of 1 for the Triceps surae and Hamstring muscle groups but and had an ankle plantarflexion contracture of 0 degrees (no dorsiflexion range) and a knee flexion contracture of 10 degrees. She had previously worn an AFO but was no longer required to do so at the time of data collection. She had also had previous surgeries and serial plaster casting on her lower limb. Child 10 underwent the intervention in weeks 5-7.

Table 30: Child 10 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**2 m post**
	b	ni	ni	ni	ni	*i*	*i*	*i*	ni	p
Balance	29	28	31	35	38	*36*	*38*	*39*	38	39
RS and A	30	25	27	25	29	*25*	*22*	*25*	26	27
TUDS	16.98	17.65	16.87	17.83	15.51	*20.73*	*21.23*	*20.35*	17.7	17
VAS	100	100	100	100	100	*100*	*75*	*95*	100	100

University of Cape Town

Figure 13: Child 10 Balance, Running Speed and Agility and TUDS

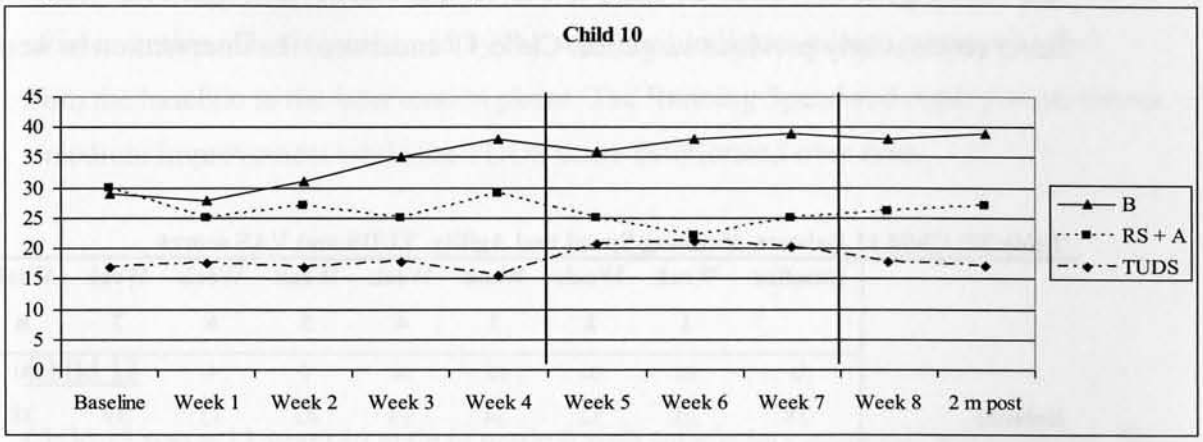


Table 31: Child 10 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	0.90	0.12	Medium improvement
RS + A	0.13	0.11	Medium deterioration
TUDS	1.00		Large deterioration
VAS	0.17	0.17	Medium deterioration

Child 10's AUC for the Balance score shows a medium treatment effect. However, an increasing trend can already be seen in the baseline phase. The Running Speed and Agility, TUDS and VAS scores reveal a marked deterioration.

Child 11

Child 11 was an 11 year old female in grade 5 with unsatisfactory academic achievement. She was one of the only two children in the sample who had a congenital hemiplegia. Her hemiplegia was right-sided and she was classified at Level I on the GMFCS. She was awarded an MAS score of 1 for the Triceps surae muscle group but

University of Cape Town

had full range of motion at the ankle and knee. She had never worn an AFO and had never received any previous surgeries. Child 11 underwent the intervention in weeks 5-7.

Table 32: Child 11 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	b	ni	ni	ni	ni	*i*	*i*	*i*	ni	p
Balance	28	31	32	34	33	*42*	*35*	*39*	38	39
RS and A	37	33	40	35	37	*39*	*37*	*38*	41	43
TUDS	11.2	15.21	14.55	13.29	13.08	*14.75*	*14.1*	*13.3*	13.87	13.24
VAS	100	50	90	90	80	*100*	*80*	*80*	80	70

Figure 14: Child 11 Balance, Running Speed and Agility and TUDS

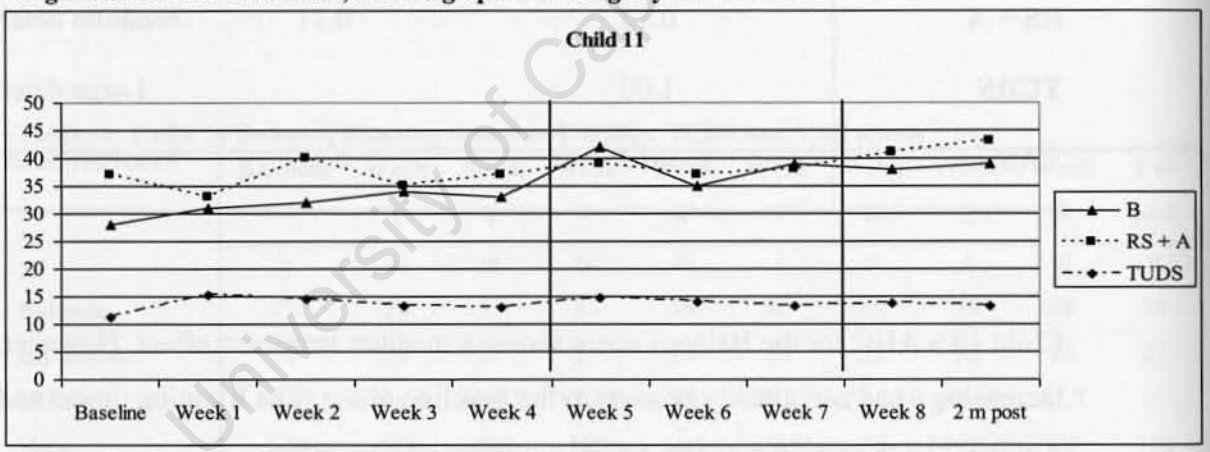


Table 33: Child 11 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	1.00		Large improvement
RS + A	0.73	0.20	Medium improvement
TUDS	0.67	0.22	Medium deterioration
VAS	0.50	0.25	No change

University of Cape Town

The graph suggests a marked improvement in Child 11's Balance score during the time of intervention. This is confirmed by the AUC that indicates a large treatment effect from the baseline to the intervention phase. The Running Speed and Agility score shows a medium improvement while the TUDS score deteriorated over time.

Child 12

Child 12 was a 13 year old male in grade 6 with satisfactory academic achievement. He had a right-sided hemiplegia and was classified at Level I on the GMFCS. He was awarded an MAS score of 1 for the Triceps surae and a 1 for the Hamstring muscle groups. He had a plantarflexion contracture of 0 degrees (no dorsiflexion range) but full range of motion at the knee joint. He had never been required to wear an AFO but had had previous surgery on his lower limb. Child 12 underwent the intervention in weeks 3-6. The intervention had to be extended since the child missed 3 Wii Fit sessions in week 4.

University of Cape Town

Table 34: Child 12 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**2 m post**
	b	ni	ni	*i*	*i*	*i*	*i*	ni	ni	p
Balance	45	43	42	*41*	*42*	*47*	*44*	45	46	47
RS and A	40	39	40	*45*	*44*	*41*	*45*	46	47	48
TUDS	17.7	16.91	14.53	*13.96*	*17.84*	*17.76*	*14.55*	17.33	16.94	19.34
VAS	95	100	95	*100*	*100*	*100*	*100*	100	100	100

Figure 15: Child 12 Balance, Running Speed and Agility and TUDS

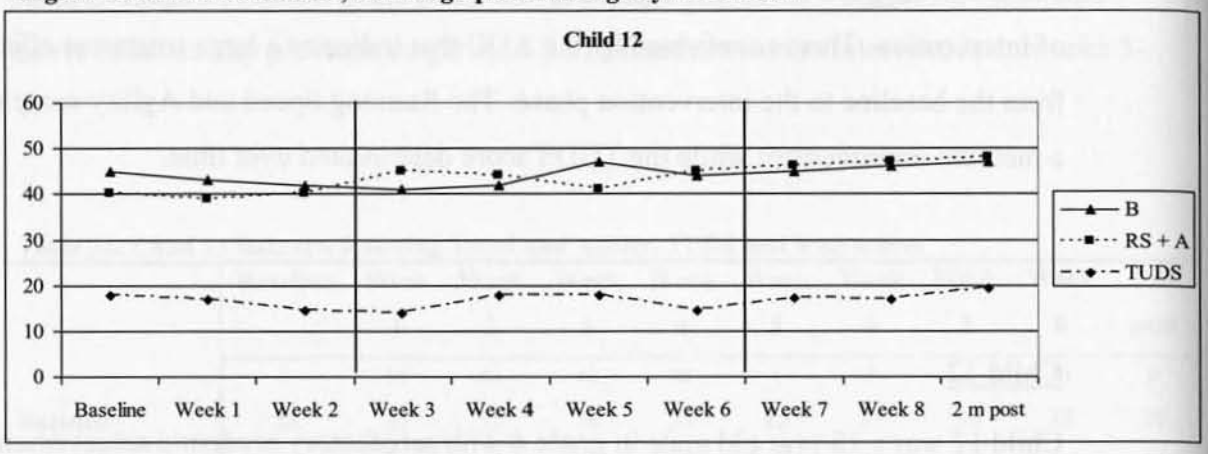


Table 35: Child 12 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	0.46	0.25	Small deterioration
RS + A	1.00		Large improvement
TUDS	0.58	0.26	Small deterioration
VAS	0.83	0.16	Medium improvement

Child 12 showed a large treatment effect on the Running Speed and Agility score. This improvement corresponds with the intervention phase. The TUDS score demonstrates a medium improvement while the Balance and VAS scores show a deteriorating trend.

Child 13

Child 13 was a 12 year old female in grade 5 with satisfactory academic performance. She had a right-sided hemiplegia and was classified at Level II on the GMFCS. She was awarded MAS scores of 1 for the Triceps surae and Hamstring muscle groups and a 1 for the Quadriceps muscle group. She had a plantarflexion contracture of 10 degrees but

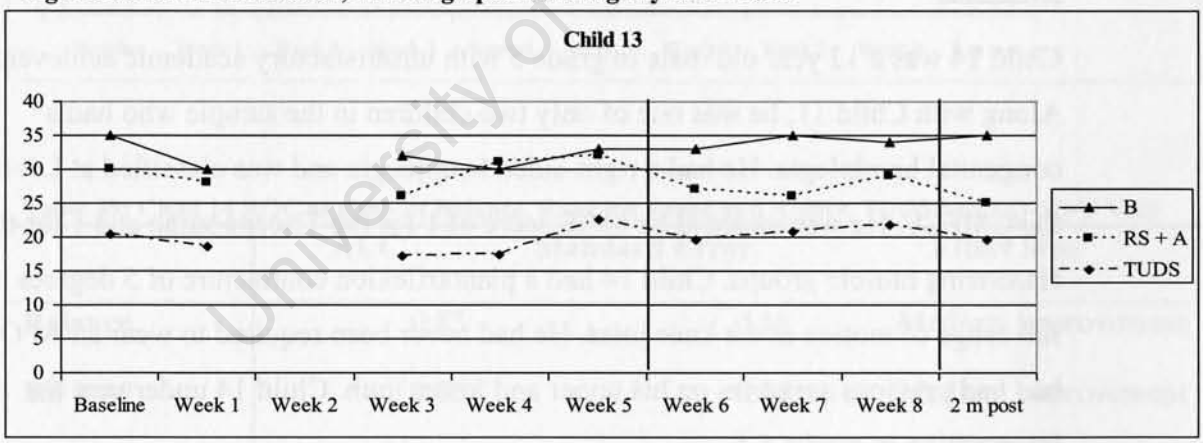
University of Cape Town

full range of motion at the knee joint. She used to have an AFO but was not required to wear one at the time of data collection. She did however wear a heel-raise orthotic on the affected side. She had had previous surgery on her lower limb. Child 13 missed a baseline measurement session in week 3 since she was absent from school that whole week. The child underwent the intervention in weeks 6-8.

Table 36: Child 13 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**2 m post**
	b	ni	ni	ni	ni	ni	*i*	*i*	*i*	p
Balance	35	30		32	30	33	*33*	*35*	*34*	35
RS and A	30	28		26	31	32	*27*	*26*	*29*	25
TUDS	20.35	18.57		17.17	17.5	22.62	*19.52*	*20.86*	*21.72*	19.53
VAS	100	100		100	100	100	*100*	*100*	*100*	100

Figure 16: Child 13 Balance, Running Speed and Agility and TUDS



University of Cape Town

Table 37: Child 13 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	0.80	0.17	Medium improvement
RS + A	0.23	0.19	Medium deterioration
TUDS	0.73	0.21	Medium deterioration
VAS	0.50	0.00	No change

Child 13 showed a medium improvement on the Balance score but a medium deterioration on the Running Speed and Agility as well as the TUDS scores. Child 13 complained of a headache in week 5. No change was seen on the VAS score.

University of Cape Town

Child 14

Child 14 was a 12 year old male in grade 5 with unsatisfactory academic achievement. Along with Child 11, he was one of only two children in the sample who had a congenital hemiplegia. He had a right-sided hemiplegia and was classified at Level II on the GMFCS. He was awarded an MAS score of 1 for the Triceps surae and 1 for the Hamstring muscle groups. Child 14 had a plantarflexion contracture of 5 degrees but had full range of motion at the knee joint. He had never been required to wear an AFO but had had previous surgeries on his upper and lower limb. Child 14 underwent the intervention in weeks 6-8.

Table 38: Child 14 Balance, Running Speed and Agility, TUDS and VAS scores

	Baseline	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	2 m post
	b	ni	ni	ni	ni	ni	*i*	*i*	*i*	p
Balance	39	35	36	39	38	38	*38*	*40*	*42*	39
RS and A	24	23	23	27	27	27	*26*	*28*	*29*	28
TUDS	25.64	21.7	26.52	15.18	16.26	17.56	*16.95*	*20.88*	*17.11*	18.91
VAS	100	90	100	100	80	95	*100*	*100*	*100*	100

Figure 17: Child 14 Balance, Running Speed and Agility and TUDS

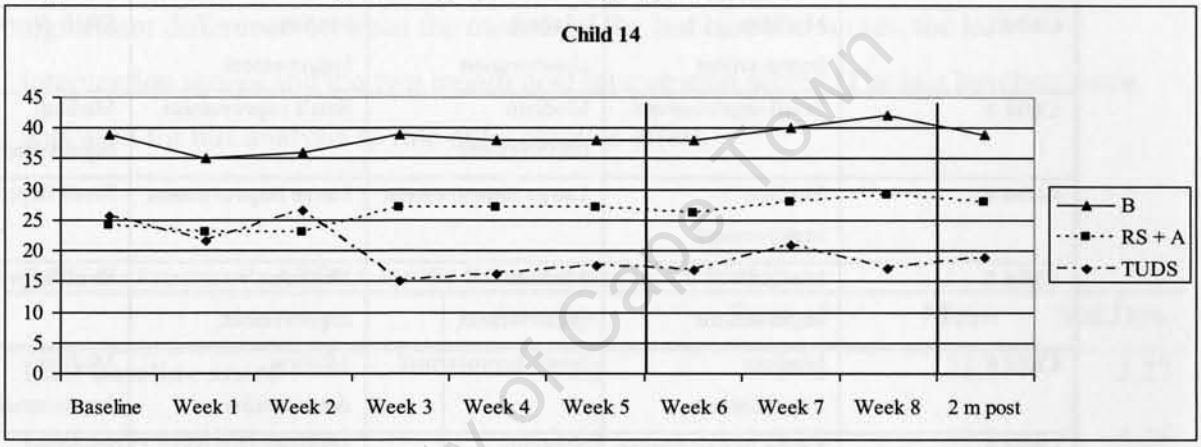


Table 39: Child 14 ROC analysis of Balance, Running Speed and Agility, TUDS and EQ-5D-Y VAS

	AUC	Standard Error	Effect Size
Balance	0.83	0.18	Medium improvement
RS + A	0.83	0.18	Medium improvement
TUDS	0.39	0.21	Small improvement
VAS	0.75	0.11	Medium improvement

Child 14 shows medium treatment effects in Balance as well as Running Speed and Agility and VAS scores. Looking at the graph, it appears that this improvement corresponds with the onset of intervention.

University of Cape Town

4.2.3 Treatment effect

The table below summarises the treatment effect sizes on the different outcome scores for each child.

Table 40: Treatment effect sizes

Child	Balance	Running Speed and Agility	TUDS	VAS
Child 1	Medium improvement	Small improvement	Small improvement	Small improvement
Child 2	Medium improvement	*Medium deterioration*	Medium improvement	*Small deterioration*
Child 3	Small improvement	Medium improvement	Small improvement	Medium improvement
Child 4	Medium improvement	**Large improvement**	**Large improvement**	Small improvement
Child 5	Medium improvement	Medium improvement	Medium improvement	Small improvement
Child 6	Medium improvement	Small improvement	*Medium deterioration*	Medium improvement
Child 7	**Large improvement**	Medium improvement	Medium improvement	Medium improvement
Child 8	Small improvement	**Large improvement**	*Medium deterioration*	*Medium deterioration*
Child 9	**Large improvement**	Medium improvement	Medium improvement	*Large deterioration*
Child 10	Medium improvement	*Medium deterioration*	*Large deterioration*	*Medium deterioration*
Child 11	**Large improvement**	Medium improvement	*Medium deterioration*	No Change
Child 12	*Small deterioration*	**Large improvement**	*Small deterioration*	Medium improvement
Child 13	Medium improvement	*Medium deterioration*	*Medium deterioration*	No Change
Child 14	Medium improvement	Medium improvement	Medium improvement	Medium improvement

University of Cape Town

Eleven of the 14 children in this study demonstrated a medium to large improvement on the Balance score. Nine children demonstrated medium to large improvements on the Running Speed and Agility measure while medium to large improvements were only seen in six children on the TUDS score. Five children showed medium to large improvements on the EQ-5D-Y VAS score.

4.2.4 Post-hoc analysis of treatment effect

A Friedman's ANOVA and post-hoc analysis were used to establish whether there was a significant difference between the median of the last baseline scores, the last intervention scores and the two month post intervention scores. The last baseline score was used for this analysis to rule out a practice effect.

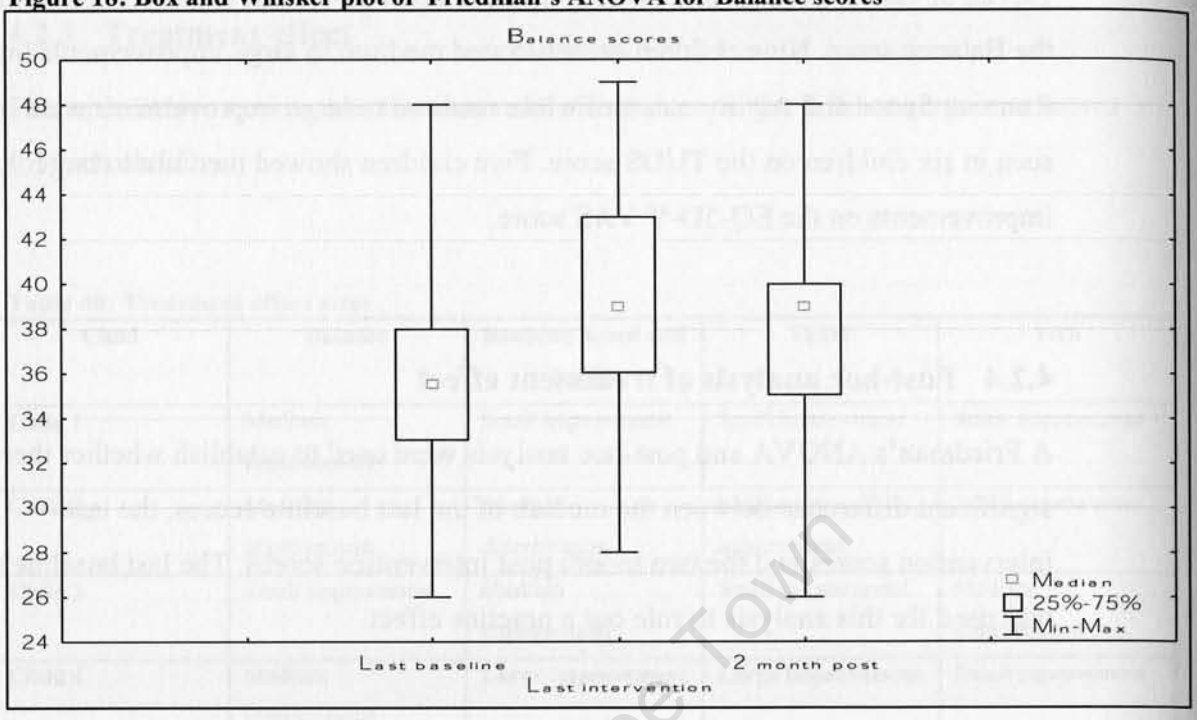
University of Cape Town

Table 41: Friedman's ANOVA for the Balance Score (p = 0.00051)

	Average	Sum of	Mean	Std.Dev.
Last baseline score	1.25	17.5	36.1	5.27
Last intervention score	2.64	37.0	39.3	5.25
2 m post score	2.11	29.5	37.9	6.24

The results of Friedman's ANOVA of the abovementioned Balance scores were accompanied by a p value of 0.00051 indicating that there was a significant difference between at least 2 of the scores under investigation.

Figure 18: Box and Whisker plot of Friedman's ANOVA for Balance scores



Post-hoc analysis of the scores revealed that there was a significant difference between the last baseline scores and the last intervention scores indicating that participants improved significantly from the baseline to the end of the intervention phase on the Balance outcome measure.

Table 42: Post-hoc analysis of Balance scores

	Valid	T	Z	p-value
Last baseline score and last intervention score	14.0	0.0	3.296	0.001
Last baseline score and two month post score	11	7.50	2.27	0.02
Last intervention score and two month post score	12.0	18.50	1.608	0.108

University of Cape Town

Similarly the participants improved from the last baseline to the two month measurement. The difference between the last intervention score and the two month post intervention score was not significant. This indicates that the median Balance score dropped somewhat after intervention but was still significantly different from the median baseline Balance scores. As a result it can be assumed that children retained the gains that were made on the Balance outcome measure.

The results of the Friedman's ANOVA for mean Running Speed and Agility, TUDS and VAS scores showed no significant differences between the last baseline scores, the last intervention scores and the two month post scores.

Table 43: Friedman's ANOVA for the Running Speed and Agility scores (p = 0.61)

	Average	Sum of	Mean	Std.Dev.
Last baseline score	1.79	25.0	31.1	6.40
Last intervention score	2.14	30.0	32.7	7.24
2 m post score	2.07	29.0	32.2	7.98

Table 44: Friedman's ANOVA for the TUDS scores (p = 0.61)

	Average	Sum of	Mean	Std.Dev.
Last baseline score	1.86	26.0	16.8	5.17
Last intervention score	2.21	31.0	17.3	5.06
2 m post score	1.93	27.0	15.9	3.89

University of Cape Town

Table 45: Friedman's ANOVA for the VAS scores (p = 0.90)

	Average	Sum of	Mean	Std.Dev.
Last baseline score	1.86	26.0	16.8	5.17
Last intervention score	2.21	31.0	17.3	5.06
2 m post score	1.93	27.0	15.9	3.89

4.2.5 Variables related to Improvement

Balance was the only outcome measure that demonstrated notable improvements following the Nintendo Wii Fit intervention. It was investigated whether variables related to the children's Wii Fit training, demographics or medical history were associated with improvements on the Balance score.

4.2.5.1 Wii Fit training time:

Total Wii Fit practice time was recorded on a weekly basis (Table 13). The difference between the last intervention Balance score and the last baseline Balance score was calculated. A Spearman's Rank Order correlation was used to establish whether this was correlated with Wii Fit training time. No association was found between total Wii Fit training time and difference in Balance score. Therefore it appears that the Wii Fit training time was not correlated with improvement on the Balance measure. No correlations were found between Wii Fit training time and the remaining three outcome measures.

University of Cape Town

Table 46: Spearman's Rank Order correlation for Balance score difference and Wii Fit training time

	Valid	Spearman	t(N-2)	p-value
Balance score difference and Wii Fit training time	14.0	0.034	0.118	0.908

4.2.5.2 Demographic and Medical variables:

A Chi-Square analysis was run of medical information against the degree of improvement on an outcome measure. The only significant associations that were found were between the Running Speed and Agility score and "Academic Achievement" ($p = 0.038$) and the TUDS score and "AFO" ($p = 0.042$).

Table 49 suggests that children with satisfactory academic achievement were more likely to show no change than they were to show an improvement on the Running Speed and Agility measure whereas all children with unsatisfactory academic achievement demonstrated an improvement on the Running Speed and Agility measure.

University of Cape Town

Table 47: Cross-tabulation of Running Speed and Agility and Academic Achievement

		Academic Achievement		
		Satisfactory	Unsatisfactory	Total
RSandA	No Change	5	0	5
	Improvement	4	5	9
Total		9	5	14

Table 48: Chi-Square analysis of Running Speed and Agility and Academic Achievement

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.321[a]	1	.038		

Table 51 suggests that children who were required to wear an AFO were more likely to improve on the TUDS score whereas those that did not wear an AFO or wore one previously were less likely to improve on the TUDS score.

Table 49: Cross-tabulaton of TUDS and AFO

		AFO			
		No	No anymore	Yes	Total
TUDS	No Change	5	3	0	8
	Improvement	3	0	3	6
Total		8	3	3	14

Table 50: Chi-Square analysis of TUDS and AFO

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.344[a]	2	.042

University of Cape Town

A Fisher's exact analysis was done to determine whether there was an association between improvement on the Balance score and improvement on the Running Speed and Agility score. No association was found (p = 0.23).

Table 51: Cross-tabulation of Balance and Running Speed and Agility score outcomes

		Running Speed and Agility		
		No change	M/L Improvement	Total
Balance	No change	0	3	3
	M/L Improvement	5	6	11
Total		5	9	14

4.2.6 Gaming Score

Each child's Wii Fit scores were documented during Wii Fit training. The Wii Fit scores were found to be quite variable and were therefore not used as an outcome measure. However, it was decided that it would be interesting to investigate whether children with cerebral palsy were able to improve their Wii Fit scores over time. The Bubble game requires multidirectional balance reactions as opposed to anteroposterior and mediolateral reactions only. Therefore, the Bubble game was used as a representative game to investigate whether the median gaming score increased from the first to the last practice session. A Wilcoxon matched pairs test was used for this purpose.

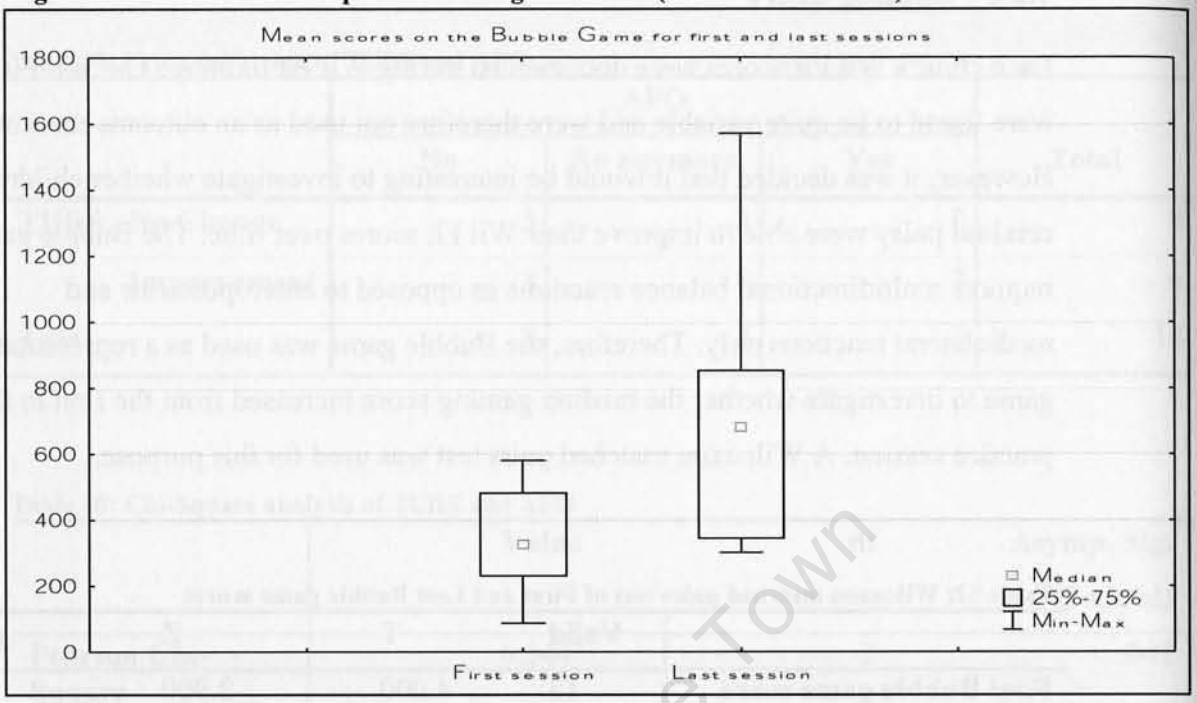
Table 52: Wilcoxon matched pairs test of First and Last Bubble game scores

	Valid	T	Z	p-value
First Bubble game score and Last Bubble game score	13	4.000	2.900	0.004

The p value of 0.004 indicates that the median Bubble game score increased significantly from the first to the last practice session. This indicates that children were able to learn and improve on the Balance games.

University of Cape Town

Figure 19: Box and Whisker plot of Bubble game scores (first and last session)



Since the Balance score was the only score that improved significantly, a Spearman's Rank Order correlation was used to establish whether improvement on the Bubble game was correlated with improvement on the Balance score. The p value of 0.53 demonstrates that this was not the case.

Table 53: Spearman's Rank Order correlation of Bubble game score and Balance score

	Valid	Spearman	t(N-2)	p-value
Difference in Bubble game score and Difference in Balance score	14	-0.19	-0.65	0.53

University of Cape Town

4.2.7 Therapy preference

Each child was asked to comment on whether they preferred conventional physiotherapy or whether they preferred playing the Wii Fit games as a substitute for therapy. As this was not meant to be a qualitative assessment, children were not asked to give reasons for their therapy preference. Only four of the 14 children said that they preferred physiotherapy over the Nintendo Wii Fit training. The remaining 10 all enjoyed the Wii Fit training more than conventional physiotherapy.

Table 54: Individual therapy preferences

Child	Comment
Child 1	Preferred conventional physiotherapy over Wii Fit.
Child 2	Preferred Wii Fit over conventional physiotherapy
Child 3	Preferred Wii Fit over conventional physiotherapy
Child 4	Preferred Wii Fit over conventional physiotherapy
Child 5	Preferred conventional physiotherapy over Wii Fit.
Child 6	Preferred Wii Fit over conventional physiotherapy
Child 7	Preferred Wii Fit over conventional physiotherapy
Child 8	Preferred Wii Fit over conventional physiotherapy
Child 9	Preferred conventional physiotherapy over Wii Fit
Child 10	Preferred conventional physiotherapy over Wii Fit
Child 11	Preferred Wii Fit over conventional physiotherapy
Child 12	Preferred Wii Fit over conventional physiotherapy
Child 13	Preferred Wii Fit over conventional physiotherapy
Child 14	Preferred Wii Fit over conventional physiotherapy

University of Cape Town

University of Cape Town

5. Discussion

The effect of the Nintendo Wii Fit on the balance control and gross motor function of children with spastic hemiplegic cerebral palsy was investigated. The objectives were to see whether a Nintendo Wii Fit intervention of 25 minutes, four times a week over three weeks would reduce impairments in balance control, reduce activity limitations by improving running speed and agility as well as stair climbing and result in an improvement in self-perceived health-related quality of life. The last objective was to determine whether any changes seen on the outcome measures would be retained over a period of 8-10 weeks post-intervention cessation.

Medium to large improvements in balance were found in 11 of the 14 children under investigation. The change in balance score was found to be significant and was retained for 2 months after intervention cessation. Results on the Running Speed and Agility, TUDS and EQ-5D-Y VAS outcome measures were more variable and not significant.

Graphical analysis revealed trends that were suggestive of a practice effect in four of the 14 children under investigation (see section 5.3.1 for details). When questioned, most of the children commented that they preferred the Nintendo Wii Fit to conventional physiotherapy. Although the Wii Fit gaming score was not used as an outcome measure, it was found that children were able to improve their gaming score therefore demonstrating motor learning on the Wii Fit balance board. However, amount of improvement on the Wii Fit games was not correlated with improvement on the Balance score.

The nature of the study sample and the external validity of the findings are discussed below. The results from each of the outcome measures are then discussed under their

University of Cape Town

individual sub-headings. Limitations of the study are presented and finally recommendations for future studies are made.

5.1 Sample

The two children who were excluded from the initial sample of 16 may have introduced a bias to the study sample, however reasons for exclusion were unrelated to the study as one child fell ill while another was put into a plaster cast at the time of data collection. Therefore their exclusion is unlikely to have influenced the results of this study.

In other, larger studies investigating children with hemiplegia, males generally outnumbered females [86 247 248] and this is in accordance with the sample under investigation. Literature on hemiplegic cerebral palsy varies with regards to the proportion of children classified at Level I or II [86 247 248]. Therefore the group of children in this study may be typical of a group of school-aged children with hemiplegic cerebral palsy. Although the findings from this study may serve as indicators for future studies on other population groups, the external validity is limited to high functioning children with spastic hemiplegic cerebral palsy.

University of Cape Town

5.2 Individual outcome measure results

5.2.1 Balance

The intervention resulted in a medium to large improvement in all but three of the 14 children under investigation and this was found to be an overall statistically significant improvement from baseline to the end of intervention. These improvements were retained 2 months after the intervention had ceased. Similar improvements in balance were also reported in the study by Nitz et al (2009 – refer to section 2.4.4) following Wii Fit training in 30-60 year old healthy women.

A study by Hartveld and Hegarty (1996) also demonstrated similar results when weightshift practice was used to improve the standing balance of four children with diplegic CP [249]. Children underwent weight shift training with computerised feedback five times a week for half an hour a day over a 70 day period. Similar to the intervention schedule in this study, Hartveld and Hegarty used an AB single subject study design with repeated measures. Another commonality was that a single leg standing test served as the primary outcome measure of balance ability. The authors concluded that weightshift practice with the use of a balance board did improve the standing balance of children with diplegic CP [249]. These results reported in 1996 by Hartveld and Hegarty, though specific to children with diplegic cerebral palsy, seem to coincide with the findings relevant to children with hemiplegic cerebral palsy in this study.

Game-like tasks such as the Nintendo Wii Fit games seem to offer subjects affordances that they do not have in the real world. The study by Lott et al (2003 – refer to section 3.4.4) showed that the addition of a game-like task resulted in much larger COP excursions than those seen in a real world reaching scenario. It was suggested that subjects were more motivated to reach further in response to performance feedback in the game-like scenario [60]. The improving trends in balance seen following the Wii Fit intervention in this study may have been due to similar increases in confidence and motivation stimulated during gaming.

A further study by Lott et al (2003 - refer to section 3.4.4) showed that during a virtual snow boarding game, a hemiplegic subject's weight bearing time on the paretic limb had increased by 18% within 12 minutes of gaming [60]. This fairly rapid and substantial increase in weight bearing symmetry is likely to have occurred with the children in this study during Wii Fit gaming. Unfortunately no measure of weight bearing symmetry was included as an outcome measure. It may be postulated however, that such weight shifting practice might have contributed to the gains seen in the balance control of children in this study.

University of Cape Town

Learnt disuse is a phenomenon seen in children with hemiplegic cerebral palsy. It was therefore anticipated that children with hemiplegia would be a target group that might benefit from the active engagement of the hemiplegic side of the body during Wii Fit gaming. Balance training activities may require the patient to shift the centre of mass but not necessarily the centre of pressure. This allows for continued bias towards the unaffected side. The Nintendo Wii Fit however requires the player to shift weight onto the hemiparetic leg (thereby shifting the centre of pressure), while engaging the hemiparetic side of the trunk for balance and equilibrium reactions. If this is not done, the Wii balance board does not react to movement and the player cannot engage in gaming. Constraint Induced Movement Therapy (CIMT) studies have demonstrated that neural plasticity and cortical re-organisation may take place following active movement of the affected limb. Criticism of CIMT however includes that children are required to wear a restraint for up to 6 hours a day and that the gains in function of the affected limb may come at the expense of disuse of the unaffected limb [250]. The Wii Fit however stimulates the use of the hemiparetic side without constraining the use of the non-paretic side. In this sense, gains in balance control may have come about due to the increased integration of the paretic side during Wii Fit gaming.

In addition to the "forced use" of the affected side, use of the unaffected side of the body in children with spastic hemiplegia may facilitate motor learning. Studies on force planning have shown that practice with the non-paretic side improves force planning on the paretic side [116]. Therefore the information gained from weight shift to the unaffected side may aid in force planning when shifting weight to the affected side as was seen in upper limb studies on force planning [116]. As a result, the Wii Fit Balance board may have aided in the improvement of motor and force planning which may have resulted in the balance improvements that were observed.

Although the improving trends in Balance discussed here are promising, it must be considered that the reliability of the Balance outcome measure was poor and that this may have influenced the results.

University of Cape Town

Looking at the variables associated with improvement, one might anticipate Wii Fit training time to be positively associated with performance on the outcome measures. Active repetition is one of the fundamental components of motor learning [57 251], therefore one would expect a greater amount of practice time to result in greater improvements in balance and mobility. However, this was not the case. The above-mentioned study by Lott et al (2003) showed that a hemiplegic subject was able to improve his symmetrical weight bearing by 18% within 12 minutes of virtual reality gaming. It is possible that such improvements in balance control also take place after only a limited time of gaming and as a result small differences in the amount of training time may not have had an influence on the child's performance on the balance score. If this had been the case, then graphs of repeated measures would depict a sudden increase on the outcome measures that would plateau and remain stable, however, visual analysis of the line graphs does not suggest such a phenomenon. Conversely, it is possible that the brevity of the intervention period did not allow for an association between Wii Fit training time and performance on the outcome measures to be revealed. It would be interesting to investigate whether an extension of the intervention period to 6 weeks would demonstrate a change in the relationship between Wii Fit training time and performance on the outcome measures.

University of Cape Town

The improvements seen on the Bubble game indicated that children were able to better their Wii Fit gaming score. This means that children with cerebral palsy demonstrate Wii Fit gaming skill acquisition over time and that Wii Fit gaming is a feasible activity for children with cerebral palsy in terms of motor learning.

Although children had the ability to improve their Wii Fit score over time, there was no association between the Wii Fit score and the outcome measure scores. This indicates that doing well on the Wii Fit games does not necessarily predict improvements in balance and gross motor function. Possible reasons for this are discussed in the following section on Running Speed and Agility.

None of the demographic or medical variables were found to be associated with an improvement on the Balance outcome measure. This is surprising as one would anticipate variables such as "GMFCS level" and "Previous Surgery" to have an effect on the child's motor learning and performance on the balance outcome measure. A general lack of association between these variables may be attributed to the small sample size that is likely to have resulted in a Type II error. Only two of the demographic and medical variables were found to be associated with the Running Speed and Agility and TUDS measures. These will be mentioned under the relevant sections below.

5.2.2 Running Speed and Agility

Data analysis showed that medium to large improvements in running speed and agility were seen in nine of the 14 children in this study. According to the Friedman's Anova, this improvement in running speed and agility was not significant. However, it is likely that the small sample number may have caused a type II error to occur. The single subject study design was employed in this research project to allow for analysis of individual performance because a type II error was anticipated due to small sample numbers. Therefore, although no significant difference was detected overall, analysis of individual results does suggest a trend towards improvement in terms of running speed and agility.

University of Cape Town

This trend towards improvement in functional mobility following Wii Fit training is in accordance with the study by Deutsch et al (2008) where an adolescent with spastic diplegic cerebral palsy underwent Wii Fit training using games such as boxing, tennis, golf, bowling and baseball. It was found that visual-perceptual processing, postural control and functional mobility all improved during and post intervention [171]. If Wii Fit upper limb activities contributed to an improvement in functional mobility, then even greater gains should be anticipated in functional mobility following Wii Fit balance board training, which targets the trunk and lower limbs more than the upper limbs.

This idea is supported by a study by Liao et al (1997) who demonstrated that dynamic balance ability, specifically rapid weight shifting ability, was significantly correlated with walking function in children with diplegic cerebral palsy [252]. Eight children with spastic diplegia and 16 age matched, 5-12 year old TD peers were included in the study. Postural stability was evaluated using the NeuroCom Smart Balance Master system, which includes a force plate that measures COP. Dynamic balance was measured in the form of lateral rhythmic weight-shifting ability (moving a COP cursor rhythmically between two lateral endlines). The ability to perform rapid rhythmic shifting was found to be correlated with walking speed [252]. Therefore the trend towards improvement in running speed and agility that was seen in nine of the individuals in this study may have come about due to the intensive weight shifting practice during Wii Fit gaming.

In this study, six of the children under investigation improved on the Balance as well as the Running Speed and Agility score. However a lack of association was found between the Balance and Running Speed and Agility scores which was statistically confirmed by Fisher's exact test ($p = 0.23$) and seems contradictory since one would expect improvements in balance to lead to equally large improvements in running speed and agility, as was seen in the study by Deutsch et al (2008) where concurrent improvements in postural control and functional mobility were seen following Wii Fit training [171].

Literature on the carry-over of balance ability to functional mobility following force platform biofeedback training (which resembles the weight shifting required during Wii Fit gaming) is contradictory. A study by Sackley et al (1993) demonstrated carry-over from visual biofeedback training to motor performance while a similar study by de Weerdt et al (1989) found no improvement in functional abilities following visual biofeedback training [156]. Generalisation of new movement strategies to functional ability, following force platform biofeedback training, may therefore be limited. It is likely that the balance reactions stimulated during Wii Fit gaming may result in

University of Cape Town

significant improvents in balance but this may not necessarily translate into equally large improvements in locomotion and gross motor function, as was seen in this study.

Numerous studies involving VR rehabilitation have demonstrated that motor strategies developed during VR practice can be translated from virtual environments to the real world but carry-over depends on the task specificity of the training [62 253]. This is reflected in the results of this study since the Nintendo Wii Fit training had a more profound effect on balance control than running speed and agility, indicating that the antero-posterior, lateral and multidirectional movements trained on the Wii Fit balance board may not be entirely valid in terms of real-world requirements when performing gross motor activities such as running and jumping. Subjects may employ balance strategies during gross motor activities that differ from the strategies used during Wii Fit gaming.

Horak et al (1997) suggest that postural responses are task specific and should be assessed and treated as such [251]. In their article on the use of external postural perturbations to improve balance control, the authors warn that reactions to external perturbations during standing do not necessarily provide information on the mechanisms needed to control balance during voluntary dynamic tasks such as locomotion or stepping over obstacles. Equilibrium responses trained in relation to external perturbations may not be predictive of the patient's performance in activities of daily living [251]. Shumway-Cook also reported that two of five children who demonstrated improved postural control following similar balance training did not demonstrate improvements on the gross motor function measure [54]. Although Wii Fit training involves self-induced postural perturbations as opposed to external perturbations, it is possible that weight shift training has similar limitations in terms of transfer to functional mobility and this may have resulted in the comparatively smaller improvements on the Running Speed and Agility score.

University of Cape Town

In addition to this, the discrepancy between the Balance and Running Speed and Agility scores may indicate that the amount of Wii Fit training received by children in this study was sufficient to result in improvements in balance but not sufficient to translate to significant improvements in running speed and agility. It is possible that carry-over to gross motor function requires a greater amount of training time. The study by Deutsch et al (2008) employed a longer intervention schedule than the one that was used in this study[171]. Therefore a longer intervention period may have resulted in equally large improvements in both the Balance and the Running Speed and Agility outcome measures. Unfortunately the multiple baseline, repeated measures design restricted the researcher to a short intervention period of three weeks. Extending the intervention period would have meant reducing the sample size considerably since the researcher oly had four school terms in which to complete data collection and this was not desirable since the sample was small to begin with.

Chi-Square analysis of the Running Speed and Agility measure showed that medium to large improvements on this measure were inversely correlated with "Academic Achievement". It was found that all children with unsatisfactory academic achievement improved on the Running Speed and Agility measure while only 4 of the 9 remaining children with satisfactory academic achievement showed improvements. Seeing as none of the other demographic or medical variables were correlated with the Running Speed and Agility score, it is unlikely that these acted as extraneous variables. Therefore, it is unclear why this association occurred.

University of Cape Town

5.2.3 TUDS

In this study, six children demonstrated medium to large improvements on the TUDS score but the overall improvements were not significant. Reasons for the lack of significant improvement might be similar to those discussed under the Running Speed and Agility section. In addition to balance control, stair climbing requires a significant amount of lower limb strength and cardiovascular fitness. It is likely that Wii Fit training

did not result in great improvements on the TUDS due to the lack of task specific training.

The TUDS was chosen as an additional outcome measure of functional mobility as it was anticipated to be more challenging than the items on the Running Speed and Agility subtest and was therefore expected to be responsive to change. The TUDS is measured in seconds and is heavily dependent on the child's effort. During measurement it was found that stair climbing required a high level of exertion for these children. Children seemed more focused on energy conservation and safety as opposed to the time to completion. In addition to the lack of task specific training, improvements in the ability to negotiate stairs might have been masked by a lack of cardiovascular fitness and caution. Children may have climbed the stairs at a pace that felt safe as opposed to their fastest possible pace. Zaino et al (2004) reported the preliminary validity and reliability of the TUDS test but stressed that the responsiveness to change was yet to be examined [36]. Due to the physically taxing nature of the test, it is possible that factors such as levels of fitness and motivation influence the test-restest reliability and responsiveness to change over time of the TUDS. However, in a study by Gorter et al (2009), 13 children with cerebral palsy (GMFCS Level I and II) showed significant improvements on the TUDS following nine weeks of circuit training that focused on aerobic endurance, walking velocity and distance [254]. Therefore the small improvements on the TUDS seen in this study are more likely to be attributed to a lack of task specific training than a lack of responsiveness of the test.

Chi-Square analysis did however show an association between the TUDS score and "AFO" that suggested that children who were required to wear an AFO were more likely to improve on the TUDS score whereas those that did not wear an AFO, or wore one previously, were less likely to improve. Again this is contradictory to what may have been expected in terms of the child's impairments. These children also did not wear their AFOs during stair climbing and therefore could not have had a resultant advantage during TUDS testing. Therefore it is unclear why this association occurred.

University of Cape Town

5.2.4 The VAS of the EQ-5D-Y

In this study, five children demonstrated medium improvements in health related quality of life. No large improvements were seen on the EQ-5D-Y VAS. Post-hoc analysis showed that there were no significant differences between the baseline, last intervention and 2 month measurements. Closer inspection of the raw scores revealed that a ceiling effect occurred in the majority of the children under investigation as many indicated a VAS score of 100 at baseline measurement. Similar ceiling effects have previously been reported in relation to the EQ-5D-Y and other Visual Analogue Scales [11 255 256].

The ceiling effect may not have been the only reason for the lack of improvement on the VAS score. Although improvements in HR-QoL following VR rehabilitation have been reported in hospitalised children [68], it may have been too optimistic to hope that half an hour of Wii Fit training four times a week over the course of 3 weeks would drastically improve quality of life of children with a chronic condition such as CP. Such a short time of gaming may not have made an impression on these children in terms of their self-perceived health and well-being. These results are similar to Nitz et al's (2009) findings that demonstrated improvements in balance and strength but no improvements in the participants' sense of well-being [173]. However, Eiser and Morse (2001) suggest that it is important to incorporate a Quality of Life assessment when testing new interventions so that more informed decisions can be made about the appropriateness of treatment [216].

Four of the 14 children in this study preferred their conventional physiotherapy regime to the Wii Fit. The remaining ten children enjoyed the Wii Fit sessions more than conventional physiotherapy. Even if health related quality of life did not change on the VAS, the Wii Fit intervention might have had a positive impact on the mood and well-being of these ten children that was not detected. Kimman et al (2009) investigated the responsiveness of the EQ-5D VAS in breast cancer patients and found that the

University of Cape Town

instrument was not responsive to small changes in health [257]. Therefore, it may be questioned whether the EQ-5D VAS is an appropriate measure of change over time in the HR-QoL of children with cerebral palsy, since it may not be responsive enough to small changes. A standardised measure of enjoyment may have been more appropriate in the context of this study (this is further discussed in section 5.3.2).

5.2.5 Two month post intervention cessation measurement

One of the objectives of this study was to see whether possible improvements following the Wii Fit intervention would be retained for at least 2 months after intervention cessation. Results showed that the gains made in balance control seemed to have been retained two months after the intervention had ended. No significant differences were seen between the means of the last baseline, last intervention and two month post measure scores for any of the other outcome measures. Therefore no significant changes had occurred during and after the intervention phase.

University of Cape Town

Deutsch et al (2009) compared the use of the Nintendo Wii Fit with a standard training program in 2 individuals in the chronic phase post-stroke [258]. Both individuals received 12 one hour sessions of either a Nintendo Wii Fit program or a standard care balance and mobility program. The Wii games included boxing, bowling, baseball, ski jumping, ski slalom and tightrope walking as well as strength training (lunges) and aerobic activities. The patient who received the regular training program was required to do balance and coordination activities in sitting, standing, stepping paced with a metronome, using visual distracters, negotiating an obstacle course and using visual biofeedback. Participants were tested before training, after training and at three months after training. Both individuals benefited from their training programs. However the individual that was trained with the Wii-based program had greater improvements on the balance and mobility outcome measures whereas the individual on the standard training program had better retention of improvements 3 months after training [258]. The limited retention seen in the study by Deutsch et al (2009) might be due to the task specific

nature and lack of transferability of the strategies learnt during Wii Fit gaming. Once the Wii Fit training had ended, subjects were no longer required to use these balance strategies and subsequently might have reverted back to using older, more familiar balance strategies.

Children in this study however, largely managed to retain the gains in balance control. It is promising to see that this is the case, as longer and more intensive treatment protocols than the one used in this study may cause even greater improvements and stimulate even better balance skill retention over time.

University of Cape Town

5.2.6 Additional remarks

Five of the 14 children under investigation demonstrated improvements on all three of the impairment and mobility outcome measures. Two of these children were classified at Level I while three were classified at Level II on the GMFCS. This is surprising seeing as one might expect improvements on all three outcome measures to be seen in children classified at Level I only, since studies have shown that children with milder levels of impairment are more likely to show gains following interventions [6 51 257 259-261]. It is hypothesised that severe levels of impairment in spasticity, paresis, reduced joint range and diminished proprioception create barriers to new movement strategies [6]. Children with lower levels of impairment may have greater physical affordances to develop more efficient strategies of movement in a shorter time period. However it is possible that this phenomenon was not noticeable in this sample since children classified at Level I and II only differ marginally in terms of their impairment levels and therefore seem to have been equally likely to improve on the outcome measures.

This was substantiated by the Chi-Square analysis which showed a lack of association between the outcome measure scores and "GMFCS level". Child 1 for instance was classified as Level I but did not demonstrate a large improvement on any of the outcome measures while some of the children classified as Level II did show large improvements

on the Balance or the Running Speed and Agility measures. Therefore level of impairment could not have been the only predictor of improvement. Other factors may have influenced the child's performance such as the child's enjoyment during Wii Fit gaming which might have lead to greater involvement and motivation and therefore greater gains in balance and gross motor function.

Some of the children under investigation demonstrated deterioration on one or more of the outcome measures from the baseline to the intervention phase. A possibility might be that children initially demonstrated maximum effort upon meeting the researcher. As time progressed and the researcher became more familiar to these children, the pressure to impress might have dropped leading to a decline in performance on the outcome measures. Large deteriorations were only seen on the TUDS score for one child and on the EQ-5D-Y VAS for another. All other deteriorations were small to medium in size.

University of Cape Town

5.3 Limitations

5.3.1 Limitations in the study sample and study design

Single subject research designs (SSRDs) are useful for the rehabilitation researcher because these allow for new interventions to be investigated even when sample numbers are insufficient for an experimental and a control group. SSRDs have the potential to produce logical generality [262]. This refers to the tentative assumption that other subjects with similar characteristics would benefit from the same treatment [262]. Single subject research designs are considered to be empirical and evidence based if carried out rigorously [263]. However, in terms of statistical inference, it is not possible to conclude that gains seen in single subject research designs will be seen when the intervention is replicated in a larger population. In addition to the small sample size, the homogeneity of the sample limits generalisation [262]. Any logical generality drawn from the results of this study can only be applied to subjects with spastic hemiplegic cerebral palsy. Although the results of this study are promising in terms of balance gains, the small

sample size, the homogeneity of the sample and the absence of a control group require results from this study to be interpreted and generalised with caution. Future investigations should involve a greater number of subjects as the RCT still remains the ideal study design when testing new interventions.

An aspect that needs to be considered when performing repeated measures is the practice effect. When children are required to repeat the items on an outcome measure, they might demonstrate improvements simply because their mastery of the test items improves. A review of the BOT-2 states that a small practice effect was noted during test-retest reliability of the Body Coordination composite of the BOT-2 [214]. Subtest 5: Balance falls under this Body Coordination composite. One of the items of the Balance test is a single leg standing test (SLST). Warren et al (2006) investigated whether there was a practice effect when performing repeated measures using the SLST. Thirty-two healthy males and females (mean age 28.6 years) underwent a two week schedule of repeated measures, performing the SLST. Three measures were taken weekly over the two week period for a total of six measures. The authors report that over a 3 week period, a decrease in SLST scores was seen and that this systematic change indicates that the SLST should be interpreted with caution when used to monitor the impact of physiotherapy interventions. Although the author mentions that one cannot be certain why this trend was seen, he suggests that this trend is likely to have occurred as a result of a practice or learning effect [30]. The subjects in Warren's study were tested three times a week. This might have influenced the amount of learning taking place as a result of practice. A study by Falleti et al (2006) investigated the repeated assessment of a cognitive function test in Forty-five adults (18-40 years). It was found that when subjects were given the test at 10 minute test-retest intervals, their performance stabilised after two trials. When subjects were given a one week interval between test trials, practice effects were reduced. In this study, the outcome measures were only performed once a week. As a result, any possible practice effects may have been diminished somewhat by the week long break in the administration of the outcome measures. Nevertheless, a practice effect cannot be ruled out. Looking at the line graphs, four of the 14 children demonstrated a trend suggestive of a practice effect in at least one

University of Cape Town

of the outcome measures in that improvement appeared to take place before the institution of intervention (Child 2: Balance; Child 3: Balance; Child 6: Balance and Running Speed and Agility; Child 10: Balance).

5.3.2 Limitations in the instrumentation chosen

In addition to a possible practice effect, outcome measures that assess balance have repeatedly been shown to be unstable and unreliable [4]. There are few balance outcome measures that have good psychometric properties [4]. Test-retest Reliability of the BOT-2 Subtest 5: Balance is low to moderate (r = .45 - .61) [188]. Therefore the results from this outcome measure may have to be interpreted with caution. Future undertakings to assess balance and postural stability might benefit from an outcome measure with more satisfactory psychometric properties. In their study on test-retest reliability of balance tests in children with cerebral palsy, Liao et al (2001), like other studies, found that the balance subtest of the BOTMP was unreliable however two of the test items were found to be highly reliable with 100% agreement [4]. These items were: standing on the preferred leg and walking forward on a walking line. The authors suggest that these items may be considered reliable when used in isolation as clinical assessment tools in children [4]. As mentioned above though, the single leg standing test has been shown to be associated with a practice effect in healthy subjects [30]. This should be taken into account when considering the use of the SLST as the only measure of balance ability.

The items on the BOT-2 Subtest 5: Balance, are designed to measure static balance in standing however Nintendo Wii Fit gaming requires subjects to rapidly shift their weight from side to side. Skills gained from weight shifting practice should ideally be assessed with an outcome measure that challenges the subject in terms of weight shifting activity. A study by Cheng et al (2004) demonstrated that dynamic balance training improved dynamic balance measures but had no effect on static balance measures in hemiplegic stroke patients [264]. Although this contradicts the findings of this study, one might question whether a measure of dynamic balance would have been more responsive to

University of Cape Town

changes in balance ability than the Balance Subtest of the BOT-2. The study by Liao et al (1997) also demonstrated a correlation between weight shifting ability and functional mobility. Therefore, it may have been useful to include an outcome measure that assesses rapid weight shifting ability in addition to the items on the BOT-2.

In addition to the limitations of the BOT-2 as a measure of balance ability, the large number of items on Subtest 5 and 6 of the BOT-2 may have impacted on the children's level of motivation during the measurement sessions. Completing the same extensive battery of tests once a week over nine weeks may have resulted in complacency and disinterest and therefore an inaccurate reflection of motor performance. Future studies should resort to more concise outcome measures with fewer test items.

When playing the Nintendo Wii Fit games, the player is required to shift weight onto the affected limb. Movement of the trunk alone and therefore movement of the centre of gravity will not make the balance board react appropriately. As a result, the Nintendo Wii Fit is likely to elicit gains in symmetrical weight bearing and improved proprioception, motor planning and force grading. Initially, it was thought that the symmetrical weight bearing could be assessed from week to week by using the Nintendo Wii Fit body test but this test was found to be unreliable and therefore unfit as an outcome measure. No alternative measure of symmetrical weight bearing was found in time for data collection. Future investigations into the effect of the Nintendo Wii Fit on the symmetrical weight bearing of children with hemiplegia might yield interesting results if force plate measurements are included as an outcome measure.

Although children were asked whether they preferred regular physiotherapy over the Nintendo Wii Fit therapy, no objective measure of motivation or enjoyment was included. It has been demonstrated that movement strategies are associated with motivational levels [265]. A study by Levac et al (2010) however found that motivation to succeed at gaming did not affect the relationship between Wii Fit game play experience

University of Cape Town

and movement quantity and quality [265]. Of the four children who expressed that they preferred conventional physiotherapy, only one demonstrated a large improvement on the Balance score. This may indicate that motivation during Wii Fit training may have influenced training outcome. It would have been interesting to see whether children who improved significantly on the outcome measures also expressed greater enjoyment on a standardised measure of enjoyment.

5.3.3 Limitations in the intervention schedule

Although 11 of the 14 children in this study demonstrated a medium to large improvement on the balance outcome measure, large improvements in balance control were only seen in three of the 14 children under investigation. It is possible that the chosen treatment schedule might have been too short for large changes to occur in the remaining children who only demonstrated a medium treatment effect. Due to school terms, class time-tables and academic requirements, the researcher was limited to a certain amount of time to carry out the intervention. The study design and availability of one Wii Fit console only, imposed limitations on the size of the treatment groups. During a 9 week school term, a minimum of 3 baseline measures had to be taken which left the researcher with 6 weeks for a multiple baseline design. All children could have concurrently received the treatment for a longer period of time, however this would have prevented randomisation to different treatment schedules. As a result, the researcher would not have been blinded and this would have raised concerns regarding bias. As mentioned above, the brevity of the intervention schedule used in this study might have influenced the results. Numerous studies have shown that increased intensity of therapy leads to greater gains in motor learning [266-271]. Future studies might benefit from scheduling the Nintendo Wii Fit sessions as an extracurricular activity. In this way, longer sessions may be implemented and greater gains may be seen without having the concern of encroaching on the child's academic learning.

University of Cape Town

5.3.4 Limitations in the statistical analysis

Statistical analyses of SSRDs seem to be controversial mainly due to the small sample sizes and serial dependency of data points inherent in single subject research designs [235] [272] [273]. Although many methods of statistical analyses have been proposed, critics of the single subject research design point out that an ideal method of analysis has not yet been found [272]. There is also no consensus as to whether effect size calculations and meta-analysis are applicable to single subject research design [272]. Wolery et al (2010) compared four overlap methods for quantitatively synthesising single-subject data (PND, Pairwise data overlap squared, percentage data exceeding the median and percentage of data exceeding a median trend) with visual analysis. According to Wolery et al (2010) this had previously been done by Parker and Vannest (2007). Parker and Vannest however used a three level rating system for visual inspection (*little to no improvement, moderate improvement, strong or major improvement*) whereas Wolery et al used a binary system (*Change or No Change).* Wolery et al (2001) found that all four overlap methods had unacceptably high levels of errors [272]. As a result, Wolery et al (2010) concluded that single subject research does not currently have a suitable method of data synthesis to calculate effect size. The method of data analysis used in this study (NAP) was not included in the article by Wolery et al (2010). Parker and Vannest (2009) found this method to be superior to all other Overlap Methods. Although this method appears to be the best option thus far and was therefore the statistical method of choice, it may not yet be the ideal method for analysing single subject research data.

University of Cape Town

5.3.5 General Limitations

It should be noted that during the baseline phase the participants were receiving routine physiotherapy so that the intervention was compared to this and not to a "no treatment" condition. It was deemed unethical to deprive the children of this therapy in the baseline phase. This implies that the intervention was not compared to no treatment but to routine treatment and this could have masked the effect of the novel intervention.

The therapy that the participants were receiving was either individual or group-based physiotherapy and some had been discharged from therapy because they had plateaued in terms of their motor development. As a result there was a lack of homogeneity in the sample regarding the type of conventional therapy that children were receiving at the time of data collection. A Chi-Square analysis however showed that there was no association between the outcome measure scores and the child having undergone conventional therapy at the time of data collection or not (See Section 8.6 Chi-Square analysis tables). This means that children who had been discharged from conventional therapy were not at a disadvantage to children who were receiving either group therapy or individual therapy during the baseline phase.

In this study, the only impairments measured were joint range and level of spasticity. Spastic paresis is characterised by weakness of the muscle tissue that may be masked by spasticity [101]. Therefore, some variability would have been present in the sample with regards to lower limb muscle strength. Manual muscle testing requires an isometric contraction and this merely measures the capacity of the muscle to produce force at a particular joint angle and muscle length and cannot necessarily be extrapolated to dynamic muscle strength [274]. However, isokinetic dynamometry has been shown to be reliable in children with spastic CP [274]. Therefore it might have been informative to include isokinetic dynamometer readings of each child's Gastrocnemius, Hamstring and Quadriceps strength.

University of Cape Town

5.4 Recommendations for Wii Fit applications and future studies

Although this study was limited to children with hemiplegic cerebral palsy, the positive responses received from therapists and children during the course of this study were encouraging and suggested a versatility in the Wii Fit functions that has not yet been fully explored. It would seem that the Wii Fit was at least as effective if not more effective, than conventional physiotherapy for some of the children, since improvements in balance control were seen when conventional therapy was substituted by Wii Fit

training. Other children however demonstrated deteriorations during the intervention period and this must be considered when using the Nintendo Wii Fit as the sole form of therapy. Unfortunately it was not possible to identify variables which distinguished the children who benefited from the intervention as this would assist therapists in identifying which children would most benefit from Wii Fit training.

Although significant improvements in balance were seen, the Wii Fit did not lead to adequate improvements in gross motor function whereas one would hope that conventional physiotherapy targets function more effectively since it can be adapted to be more task specific. Therefore it is not suggested that Nintendo Wii Fit training should replace conventional physiotherapy but instead may enhance and contextualise therapy for children. Interspersing conventional therapy with intensive Wii Fit training may maximise the benefits seen in balance control. The Nintendo Wii Fit may also be seen as a more affordable and accessible alternative to balance control therapies such as hippotherapy. Other suggested uses may include scheduling ten minutes of Wii play towards the end of a therapy session. This may serve as a motivating factor for the child during the conventional Physiotherapy exercises. Therapists often use outmoded incentives such as stickers and puzzles for this purpose. These might offer encouragement but do not contribute to motor skill improvement. Using the Nintendo Wii Fit as an incentive maximises the duration of the treatment session while masking therapy as fun. Future studies are needed to further establish possible uses and ascertain the most appropriate and effective application of the Nintendo Wii Fit. Recommendations for such studies are made below.

University of Cape Town

In this study, the effect of the Wii Fit was tested solely on hemiplegic children and only the Balance games and one Aerobic game (hoola hoops) were incorporated in training. During the period of data collection, therapists were allowed to use the Wii Fit balance board with children not included in this study. One therapist commented that the Ski jumping game was particularly useful for children with diplegia. Diplegic children tend to adapt a crouched gait position with hip and knee flexion and ankle dorsiflexion [115].

The Ski-jumping game requires the player to rapidly extend the hips and knees from a flexed position in order to launch the avatar off the ski slope. This may aid in strengthening the quadriceps and gluteal muscles while reducing the time spent in a crouched position. Investigating the use of the Wii Fit for different target groups such as diplegic children might be worthwhile in future studies.

Another aspect of the Wii Fit that should be considered for future studies is the use of the Nunchuck and remote for the Wii Fit sports games that require upper limb activity. The Nunchuck is a hand-held controller that is part of the Wii Fit console. It allows the player to engage in games such as boxing, tennis, baseball and golf. Hemiplegic children with marked learned disuse and neglect of the upper limb may benefit from these video games where bilateral upper limb activity is required. These activities may be a child-friendly alternative to constraint induced movement therapy, stimulating upper limb activity without restraint of the unaffected limb.

The Wii Fit applications extend beyond the balance games used in this study. Strength training and aerobic fitness games were not included during Wii Fit training. It is possible that these games might be effective to improve strength and physical fitness in children with cerebral palsy. Future investigations to this effect would be interesting.

The type of Wii Fit games chosen from session to session might also have influenced the outcome. A study by Levac et al (2010) demonstrated that children showed significant differences in movement quantity between the soccer heading and ski slalom games. Greater center of pressure displacements were seen during the soccer heading game than during the ski slalom game [265]. This may indicate that movement requirements are game specific and that some games may improve dynamic balance more than others. Comparisons of the Nintendo Wii Fit games in terms of their benefit and ability to improve balance control might provide useful information for clinicians regarding game choices.

University of Cape Town

It is possible that the amount of verbal instruction and facilitation given by the research assistants during the intervention might have influenced the extent of the child's engagement in gaming. Instructions to research assistants allowed them to coach and facilitate the child through the first few sessions of gaming. In some cases, research assistants felt it was necessary to place their hands on the child's pelvis to guide true centre of pressure shifting as opposed to just centre of mass shifting. Studies investigating the effect of the degree of encouragement and instruction may be relevant particularly when considering the Nintendo Wii Fit as a potential tool for home-based rehabilitation where the patient is alone and has no input from the therapist.

University of Cape Town

University of Cape Town

6. Conclusion

The objectives of this study were to investigate the effect of the Nintendo Wii Fit on the balance control, gross motor function and health-related quality of life in children with hemiplegic cerebral palsy and to establish whether possible improvements would be maintained over a two month period. It was found that the Nintendo Wii Fit intervention has some potentially therapeutic effects for the balance control and gross motor function of some of the 7-14 year old children with spastic hemiplegic cerebral palsy who were included in this study. Although the Nintendo Wii Fit, as it was used in this study, seemed to have no effect on health related quality of life, these findings warrant further investigation on the efficacy of Wii Fit training for children with cerebral palsy.

Eleven of the 14 children showed medium to large improvements on the Balance score and nine children showed medium to large improvements on the Running Speed and Agility score. This is an improvement in a substantial number of the children under investigation, when taking the relatively short period of intervention into consideration. Improvements in balance were found to be significant and were sustained two months post intervention cessation. Extending the intervention period may have allowed for significant improvements to be seen in a greater number of children. It is therefore recommended that future studies investigating the effect of the Nintendo Wii Fit employ a more intensive and longer period of block therapy. Studies with greater sample numbers and control groups are also required so that results may be generalised to hemiplegic children at large.

Considering that the Nintendo Wii Fit intervention seemed to promote improvements in balance control and gross motor function, it may be seen as an affordable and accessible form of balance control therapy. Studies investigating other forms of virtual reality rehabilitation have yielded great successes and promising results. What sets this study apart from virtual reality studies is that the equipment is commercially available, cost

University of Cape Town

effective and easy to operate in contrast to specialised laboratory equipment. No extensive training is required for therapists and maintenance of the equipment is inexpensive and effortless. The versatility of the Nintendo Wii Fit has not yet been fully investigated. However, if children with hemiplegic cerebral palsy seem to benefit from this form of therapy, then children with other forms of neurological disability might benefit in a similar way. Apart from the batteries that need replacement, the Nintendo Wii Fit is a versatile, once-off expense that could be used regularly and diversely in schools and rehabilitation centers to augment conventional therapy.

Although cerebral palsy is a chronic disorder that cannot be cured, it is important that rehabilitation professionals keep finding new and exciting approaches to engage these children in movement. Novel approaches should be effective but reasonable in terms of cost, time consumption and demands made on the child. For effective motor learning to take place, therapy should not be tedious and children should be enticed to actively participate in their rehabilitation. The Nintendo Wii Fit engages children in this way. The gaming tasks add a playful and contemporary aspect to therapy. Children benefit from the challenges that are presented, with a great amount of enjoyment.

University of Cape Town

Proponents of conventional forms of therapy may question the concept of video game rehabilitation. However, looking to other fields of science for new approaches to treatment may contribute to progression in neurorehabilitation as well as remedy the current paucity in evidence based physiotherapy treatment techniques for children. Therapy with a modern edge may give these children a sense of inclusion in an era of technological advances. As the disability campaigner and activist Ken Davies once said:

"See the ability – not the disability" [275]

University of Cape Town

University of Cape Town

7. References

1. Parker RI, Vannest K. An improved effect size for single-case research: Nonoverlap of All Pairs. *Behaviour Therapy* 2009;40(4):357-67.
2. Kembhavi G, Darrah J, Magill-Evans J, Loomis J. Using the Berg Balance scale to distinguish balance abilities in children with cerebral palsy. *Pediatric Physical Therapy* 2002;14(2):92-99.
3. Kembhavi G. The Berg Balance Scale: validation in a paediatric population. University of Alberta, 2000.
4. Liao HF, Mao P, Hwang AW. Test-retest reliability of balance tests in children with cerebral palsy. *Developmental Medicine & Child Neurology* 2001;43(3):180-86.
5. Wuang Y-P, Su C-Y. Reliability and responsiveness of the Bruininks-Oseretsky Test of Motor Proficiency- Second Edition in children with intellectual disability. *Research in Developmental Disabilities* 2009;30(5):847-55.
6. Cope SM, Xue-Cheng L, Verber MD, Cayo C, Rao S, Tassone JC. Upper limb function and brain reorganization after constraint-induced movement therapy in children with hemiplegia. *Developmental Neurorehabilitation* 2010;13(1):19-30.
7. Carlberg EB, Hadders-Algra M. Postural dysfunction in children with cerebral palsy: some implications for therapeutic guidance. *Neural Plasticity* 2005;12(2-3):221-27.
8. Hsue BJ, Miller F, Su FC. The dynamic balance of children with cerebral palsy and typical developing during gait. Part I: spatial relationship between COM and COP trajectories. *Gait and Posture* 2009;29(3):465-70.
9. Barnhart RC, Davenport MJ, Epps SB, Nordquist VM. Developmental coordination disorder. *Physical Therapy* 2003;83(8):722-31.
10. *Oxford Concise Medical Dictionary* 7th ed. Oxford: Oxford Univesity Press, 2007.
11. Ravens-Sieberer U, Wille N, Badia X, Bonsel G, Burström K, Cavrini G, et al. Feasibility, reliability and validity of the EQ-5D-Y: results from a multidimensional study. *Quality of Life Research* 2010;19(6):887-97.
12. Buxton R. *Introduction to functional magnetic resonance imaging: principles and techniques*. Cambridge, UK: Cambridge University Press 2002.
13. Palisano RJ, Rosenbaum PL, Bartlett DJ, Livingston MH. Content validity of the expanded and revised Gross Motor Function Classification System. *Developmental Medicine & Child Neurology* 2008;50(10):744-50.
14. Russell DJ, Rivard L, Bartlett DJ, Rosenbaum PL. Frequently asked questions related to the motor growth curves: CanChild Centre for Childhood Disability Research, 2003:1-2.
15. Kamphuis M, Ottenkamp J, Vliegen HW, Vogels T, Zwinderman KH, Kamphuis RP, et al. Health related quality of life and health status in adult

University of Cape Town

survivors with previously operated complex congenital heart disease. *Heart* 2002;87(4):356-62.
16. Guyatt GH, Feeny DH, Patrick DL. Measuring health-related quality of life. *Annals of Internal Medicine* 1993;118(8):622-29.
17. The International Classification of Functioning, Disability and Health (ICF). http://www.who.int/classifications/icf/en/. Geneva: World Health Organization, cited 03.04.2010.
18. Thorpe DE, Valvano J. The effects of knowledge of performance and cognitive strategies on motor skill learning in children with cerebral palsy. *Pediatric Physical Therapy* 2002;14(1):2-15.
19. Clopton N, Dutton J, Featherston T, Grigsby A, Mobley J, Melvin J. Interrater and intrarater reliability of the Modified Ashworth Scale in children with hypertonia. *Pediatric Physical Therapy* 2005;17(4):268-74.
20. Stanger M, Oresic S. Rehabilitation approaches for children with cerebral palsy: overview. *Journal of Child Neurology* 2003;18(1):79-88.
21. Butler C, Darrah J. Effects of neurodevelopmental treatment (NDT) for cerebral palsy. *Develomental Medicine & Child Neurology* 2001;43(11):778-90.
22. Ottenbacher KJ, Biocca Z, DeCremer G, Gevelinger M, Jedlovec KB, Johnson MB. Quantitative analysis of the effectiveness of pediatric therapy. *Physical Therapy* 1986;66(7):1095-101.
23. Maring JR, Elbaum L. Concurrent validity of the Early Intervention Developmental Profile and the Peabody Developmental Motor Scale-2. *Pediatric Physical Therapy* 2007;19(2):116-20.
24. Kothari DH, Haley SMH, Gill-Body KM, Dumas HM. Measuring functional change in children with acquired brain injury (ABI): comparison of generic and ABI-specific scales using the Pediatric Evaluation of Disability Inventory (PEDI). *Physical Therapy* 2003;83(9):776-85.
25. Park SH, Goo JM, Jo C-H. Receiver operating characteristic (ROC) curve: practical review for radiologists. *Korean Journal of Radiology* 2004;5(1):11-18.
26. Reese NB, Bandy WD. *Joint range of motion and muscle length testing*. 2nd ed. St Louis, Missouri: Saunders Elsevier, 2009.
27. De Veaux RD, Velleman PF, Bock DE. *Stats: data and models*. Boston: Pearson Education, 2008.
28. Company HM. *The new dictionary of cultural literacy*. 3rd ed: Houghton Mifflin, 2002.
29. Kraus MW, Keltner D. Signs of socioeconomic status: a thin-slicing approach. *Psychological Science*, 2009:99-106.
30. Warren J, Schneiders AG, Sullivan SJ, Bell ML. Repeated single-limb postural stability testing elicits a practice effect. *Physical Therapy in Sport* 2006;7(4):185-90.
31. Backman CL, Harris SR. Case-studies, single subject research, and N of 1 randomized trials: comparisons and contrasts. *American Journal of Physical Medicine and Rehabilitation* 1999;78(2):170-76.

University of Cape Town

32. Beeson PM, Robey RR. Evaluating single-subject treatment research: lessons learned from the aphasia literature. *Neuropsychol Rev* 2006;16(4):161-69.
33. Murdoch B, Theodoros D. *Associated Speech, Language, and Swallowing Disorders*. San Diego, CA: Singular Thomson Learning, 2001.
34. Tecklin J. *Pediatric physical therapy*. 4th ed: Lippincott, William & Wilkins, 2008.
35. Scholtes AB, Becher JG, Beelen A, Gustaaf JL. Clinical assessment of spasticity in children with cerebral palsy: a critical review of available instruments. *Developmental Medicine & Child Neurology* 2006;48(1):64-73.
36. Zaino CA, Marchese VG, Westcott SL. Timed Up and Down Stairs Test: preliminary reliability and validity of a new measure of functional mobility. *Pediatric Physical Therapy* 2004;16(2):90-98.
37. Williams EN, Carroll SG, Reddihough DS, Phillips BA, Galea PM. Investigation of the timed "Up&Go" test in children. *Developmental Medicine & Child Neurology* 2005;47(8):518-24.
38. *The American Heritage Dictionary of the English Language* 4th ed: Houghton Mifflin Company, 2000.
39. Gould D, Kelly D, Goldstone L, Gammon J. Examining the validity of pressure ulcer risk assessment scales: developing and using illustrated patient simulations to collect the data. *Journal of Clinical Nursing* 2001;10(5):697-706.
40. Encyclopaedia Britannica http://www.britannica.com/. Academic edition ed: Encyclopaedia Britannica, cited 04.04.2010.
41. World Health Organization. http://www.who.int/about/en/. Geneva: World Health Organization, cited 03.11.2010.
42. White-Koning M, Catherine A, Dickinson HO, Thyen U, Beckung E, Fauconnier J, et al. Determinants of child-parent agreement in quality-of-life reports: a european study of children with cerebral palsy. *Pediatrics* 2007;120(4):804-14.
43. Bartlett JR, Palisano RJ. A multivariate model of determinants of motor change for children with cerebral palsy. *Physical Therapy* 2000;80(6):598-641.
44. Cimolin V, Galli M, Tenore N, Albertini G, Crivellini M. Gait strategy of uninvolved limb in children with spastic hemiplegia. *Europa Medicophysica* 2007;43(3):303-10.
45. Mewasingh LD, Sékhara T, Pelc K, Missa A, Cheron G, Dan B. Motor strategies in standing up in children with hemiplegia. *Pediatric Neurology* 2004;30(4):257-61.
46. Gorter JW, Rosenbaum PL, Hanna SE, Palisano RJ, Bartlett DJ, Russell DJ, et al. Limb distribution, motor impairment, and functional classification of cerebral palsy. *Developmental Medicine & Child Neurology* 2004;46(7):461-67.
47. Jeng SF, Holt KG, Fetters L, Certo C. Self-optimization of walking in nondisabled children and children with spastic hemiplegic cerebral palsy *Journal of Motor Behavior* 1996;28(1):15-27.

University of Cape Town

48. Fonesca ST, Holt KG, Fetters L, Saltzman E. Dynamic resources used in ambulation by children with spastic hemiplegic cerebral palsy: relationship to kinematics, energetics, and asymmetries. *Physical Therapy* 2004;84(4):344-58.
49. Gracies JM. Pathophysiology of spastic paresis. I: paresis of soft tissue changes. *Muscle Nerve* 2005;31(5):535-51.
50. Murphy N, Such-Neibar T. Cerebral Palsy Diagnosis and Management: The State of the Art. *Current Problems in Pediatric and Adolescent Health Care* 2003;33(5):146-69.
51. Woollacott MH, Shumway-Cook A. Postural dysfunction during standing and walking in children with cerebral palsy: what are the underlying problems and what new therapies might improve balance? . *Neural Plasticity* 2005;12(2-3):211-19.
52. de Graaf-Peters VB, Blaauw-Hospers CH, Dirks T, Bakker H, Bos A, Hadders-Algra M. Development of postural control in typically developing children and children with cerebral palsy: possibilities for intervention? . *Neuroscience and Biobehavioral Reviews* 2007;31(8):1191-200.
53. Smits-Engelsman BCM, Rameckers EAA, Duysens J. Children with congenital spastic hemiplegia obey Fitt's Law in a visually guided tapping task. *Experimental Brain Research* 2007;177(4):431-39.
54. Shumway-Cook A, Hutchinson S, Kartin D, Price R, Woollacott MH. Effect of balance training on recovery of stability in children with cerebral palsy. *Developmental Medicine & Child Neurology* 2003;45(9):591-602.
55. Brown GT, Burns SA. The efficacy of neurodevelopmental treatment in paediatrics: a systematic review. *British Journal of Occupational Therapy* 2001;64(5):235-44.
56. Van der Weel FR, van der Meer AL, Lee DN. Measuring dysfunction of basic movement control in cerebral palsy. *Human Movement Science* 1996;15(2):253-83.
57. Boller F, Grafman J, Robertson IH, Rizzolatti G, Cermak LS, Berndt RS, et al. *Handbook of neuropsychology*. 2nd ed: Elsevier Health Sciences, 2003.
58. Flynn S, Palma P, Bender A. Low-tech virtual reality improves function in individuals with central nervous system injury. *Journal of Neurological Physical Therapy* 2006;30(4):210-11.
59. Lange B, Flynn S, Rizzo A. Initial usability assessment of off-the-shelf video game consoles for clinical game-based motor rehabilitation. *Physical Therapy Reviews*, 2009.
60. Lott A, Bisson E, Lajoie Y, McComas J, Sveistrup H. The effect of two types of virtual reality on voluntary center of pressure displacement. *CyberPsychology & Behavior* 2003;6(5):477-85.
61. Keshner EA. Virtual reality and physical rehabilitation: a new toy or a new research and rehabilitaton tool? . *Journal of NeuroEngineering and Rehabilitation* 2004;1(8):1-2.
62. Holden MK. Virtual environments for motor rehabilitation: review. *CyberPsychology & Behavior* 2005;8(3):187-211.

University of Cape Town

63. Thornton M, Marshall S, McComas J, Finestone H, McCormick A, Sveistrup H. Benefits of activity and virtual reality based balance exercise programmes for adults with traumatic brain injury: perceptions of participants and their caregivers. *Brain Injury* 2005;19(12):989-1000.
64. Bryanton C, Bossé J, Brien M, McLean J, McCormick A, Sveistrup H. Feasibility, motivation, and selective motor control: virtual reality compared to conventional home exercise in children with cerebral palsy. *CyberPsychology & Behavior* 2006;9(2):123-28.
65. Wii-habilitation. http://www.wiihabilitation.co.uk/news.shtml#wiifit. Cheltenham: National Star College cited 01.04.2009.
66. Arthanat S, Nochajski SM, Stone J. The international classification of functioning, disability and health and its application to cognitive disorders. *Journal of Disability and Rehabilitation* 2004;26(4):235-45.
67. Sullivan E, Barnes D, Linton JL, Calmes J, Damiano D, Oeffinger D, et al. Relationships among functional outcome measures used for assessing children with ambulatory CP. *Developmental Medicine & Child Neurology* 2007;49(5):338-44.
68. McComas J, Pivik J, Laflamme M. Current uses of virtual reality for children with disabilities. In: Riva G, editor. *Virtual Environments in Clinical Psychology and Neuroscience.* Amsterdam: Ios Press, 1998.
69. Stucki G, Ewert T, Cieza A. Value and application of the ICF in rehabilitation medicine. *Disability and Rehabilitation* 2002;24(17):932-38.
70. Ustün TB, Chatterji S, Bickenbach J, Kostanjsek N, Schneider M. The International Classification of Functioning, Disability and Health: a new tool for understanding disability and health. *Disability and Rehabilitation* 2003;3-17(11-12):565-71.
71. Rauch A, Cieza A, Stucki G. How to apply the International Classification of Functioning, Disability and Health (ICF) for rehabilitation management and clinical practice. *Eur J Phys Rehabil Med* 2008;44(3):329-42.
72. Gordon LM, Keller JL, Stashinko EE, Hoon AH, Bastian AJ. Can spasticity and dystonia be independently measured in cerebral palsy? *Paediatric Neurology* 2006;35(6):375-81.
73. Andersen GL, Irgens LM, Haagaas I, Skranes JS, Meberg AE, Vik T. Cerebral palsy in Norway: prevalence, subtypes and severity. *European Journal of Paediatric Neurology* 2008;12(1):4-13.
74. Odding E, Roebroeck ME, Stam HJ. The epidemiology of cerebral palsy: incidence, impairments and risk factors. *Disability and Rehabilitation* 2006;28(4):183-91.
75. Jan MM. Cerebral palsy: comprehensive review and update. *Annals of Saudi Medicine* 2006;26(2):123-32.
76. Muraskas J, Kayhan P. The cost of saving the tiniest lives: NICUs versus prevention. *American Medical Association Journal of Ethics* 2008;10(10):655-58.
77. Vincer MJ, Allen AC, Joseph KS, Stinson DA, Scott H, Wood E. Increasing prevalence of cerebral palsy among very preterm infants: a population-based study. *Pediatrics* 2006;118(6):1621-26.

University of Cape Town

78. Panteliadis C, Tzitiridou M, Pavlidou E, Hagel C, Covanis A, Jacobi G. Congenital Hemiplegia. *Nervenartzt* 2007;78(10):1188-94.
79. van Toorn R, Laughton B, van Zyl N. Aetiology of cerebral palsy in children pesenting at Tygerberg Hospital. *South African Journal of Child Health* 2007;1(2):74-77.
80. Panteliadis CP, Strassburg HM. *Cerebral palsy: principles and management.* Stuttgart - New York: Georg Thieme Verlag, 2004.
81. Shumway-Cook A, Wollacott MH. *Motor control: translating research into clinical practice.* 3rd ed: Lippincott Williams and Wilkins, 2006.
82. Mutsaarts M, Steenbergen B, Bekkering H. Anticipatory planning deficits and task context effects in hemiparetic cerebral palsy. *Experimental Brain Research* 2006;172(2):151-62.
83. Gormley ME, O'Brien CF, Yablon SA. A clinical overview of treatment decisions in the management of spasticity. *Muscle Nerve* 1997;20(6):S14-S20.
84. O'Shea TM. Diagnosis, treatment and prevention of cerebral palsy. *Clinical Obstetrics and Gynaecology* 2008;51(4):816-28.
85. Palisano R, Rosenbaum P, Bartlett D, Livingston M. Gross Motor Function Classification System - Expanded and Revised. *Develomental Medicine & Child Neurology* 2007;39:214-23.
86. Damiano D, Abel M, Romness M, Oeffinger D, Tylkowski C, Gorton G, et al. Comparing functional profiles of children with hemiplegic and diplegic cerebral palsy in GMFCS levels I and II: are seperate classifications needed? *Develomental Medicine & Child Neurology* 2006;48(10):797-803.
87. Hadders-Algra M. General movements: a window for early identification of children at high risk for developmental disorders. *Journal of Pediatrics* 2004;145(2):S12-S18.
88. Cooley WC. Providing primary care medical home for children and youth with cerebral palsy. *Pediatrics* 2004;114(4):1106-13.
89. Zafeiriou DI. Primitive reflexes and postural reactions in the neurodevelopmental examination. *Paediatric Neurology* 2004;31(1):1-8.
90. Bouza H, Rutherford M, Acolet D, Pennock JM, Dubowitz LMS. Evolution of early hemiplegic signs in full-term infants with unilateral brain lesions in the neonatal period: a prospective study. *Neuropediatrics* 1994;25(4):201-07.
91. Uvebrant P. Hemiplegic cerebal palsy. Aetiology and outcome. *Acta Paediatrica Scandinavica. Supplement* 1988;345:1-100.
92. Eliasson A-C, Krumlinde-Sundholm L, Shaw K, Wang C. Effects of constraint-induced movement therapy in young children with hemiplegic cerebral palsy: an adapted model. *Develomental Medicine & Child Neurology* 2005;47(4):266-75.
93. MacLennan A. A template for defining a causal relation between acute intrapartum events and cerebral palsy : international consensus statement. *British Medical Journal* 1999;319(7216):1054-59.
94. Sundrum R, Logan S, Wallace A, Spencer N. Cerebral palsy and socioeconomic status: a retrospective cohort study. *Archives of Disease in Childhood* 2005;90(1):15-18.

University of Cape Town

95. Hjern A, Thorngren-Jerneck K. Perinatal complications and socio-economic differences in cerebral palsy in Sweden - a national cohort study. *BioMed Central Paediatrics* 2008;8(49):1-7.
96. Arens LJ, Molteno CD. A comparative study of postnatally-acquired cerebral palsy in Cape Town. *Develomental Medicine & Child Neurology* 1989;31(2):246-54.
97. Ostensjo S, Carlberg E, Vollestad N. Motor impairments in young children with cerebral palsy: relationship to gross motor function and everyday activities. *Develomental Medicine & Child Neurology* 2004;46:580-89.
98. Steenbergen B, Gordon AM. Activity limitation in hemiplegic cerebral palsy: evidence for disorders in motor planning. *Develomental Medicine & Child Neurology* 2006;48(9):780-83.
99. Sanger TD, Delgado MR, Gaebler-Spira D, Hallett M, Mink JW. Classification and definition of disorders causing hypertonia in childhood. *Pediatrics*, 2003:e89-e97.
100. Sheean G, McGuire JR. Spastic hypertonia and movement disorders: pathophysiology, clinical presentation and quantification. *Physical Medicine & Rehabilitation* 2009;1(9):827-33.
101. Gelber DA, Jeffery DR. *Clinical evaluation and management of spasticity.* Totowa, New Jersey: Humana Press Inc., 2002.
102. Howle JM. *Neurodevelopmental Treatment.* Laguna Beach, CA: Neurodevelopmental Treatment Association 2002.
103. Koman LA, Paterson Smith B, Shilt JS. Cerebral palsy. *The Lancet* 2004;363:1619-31.
104. Dursun E, Dursun N, Alican D. Effects of biofeedback treatment on gait in children with cerebral palsy. *Disability and Rehabilitation* 2004;26(2):116-20.
105. Brown JK, Rodda J, Walsh EG, Wright GW. Neurophysiology of lower-limb function in hemiplegic children. *Developmental Medicine & Child Neurology* 1991;33:1037-47.
106. Mohagheghi AA, Khan T, Meadows TH, Giannikas K, Baltzopoulos V, Maganaris CN. Differences in gastrocnemius muscle architecture between the paretic and non-paretic legs in children with hemiplegic cerebral palsy. *Clinical Biomechanics* 2007;22(6):718-24.
107. Moreau NG, Simpson KN, Teefey SA, Damiano DL. Muscle architecture predicts maximum strength and is related to activity levels in cerebral palsy. *Physical Therapy* 2010;90(11):1619-20.
108. Goh HT, Thompson M, Huang WB, Schafer S. Relationships among measures of knee musculoskeletal impairments, gross motor function, and walking efficiency in children with cerebral palsy. *Pediatric Physical Therapy* 2006;18(4):253-61.
109. Westcott SL, Lowes LP, Richardson PK. Evaluation of postural stability in children: current theories and assessment tools. *Physical Therapy* 1997;77(6):629-45.
110. Latash ML. *Neurophysiological basis of movement* 2nd ed: Human Kinetics, 2008.

University of Cape Town

111. Rossi S, Patane F, Scalise L, Marchionni P, Cappa P. Centre of pressure in dynamic posturography: a comparison among systems based on a pressure matrix and a force platform. *Measurement Science and Technology* 2010;21(1):1-9.
112. Roncesvalles MN, Woollacott MH, Burtner PA. Neural factors underlying reduced postural adaptability in children with cerebral palsy. *Clinical Neuroscience and Neuropathology* 2002;13(18):2407-10.
113. Coker P, Karakostas T, Dodds C, Hsiang S. Gait characteristics of children with hemiplegic cerebral palsy before and after modified constraint-induced movement therapy. *Disability and Rehabilitation* 2010;32(5):402-08.
114. Raja K, Joseph B, Benjamin S, Minocha V, Rana B. Physiological cost index in cerebral palsy. *Journal of Pediatric Orthopaedics* 2007;27(2):130-36.
115. Westcott SL, Burtner PA. Postural control in children: implications for pediatric practice. *Physical and Occupational Therapy in Pediatrics* 2004;24(1):5-55.
116. Steenbergen B, Verrel J, Gordon AM. Motor planning in congenital hemiplegia. *Disability and Rehabilitation* 2007;29(1):13-23.
117. Bottcher L, Meulengracht Flachs E, Uldall P. Attentional and executive impairments in children with spastic cerebral palsy. *Develomental Medicine & Child Neurology* 2009;52(2):e42-47.
118. Steenbergen B, Charles JR, Gordon AM. Fingertip force control during bimanual object lifting in hemiplegic cerebral palsy. *Experimental Brain Research* 2008;186(2):191-201.
119. Van Zelst BR, Miller MD, Russo RN, Murchland S, Crotty M. Activities of daily living in children with hemiplegic cerebral palsy: a cross-sectional evaluation using the Assessment of Motor and Process Skills. *Develomental Medicine & Child Neurology* 2006;48(9):723-27.
120. Mackey AH, Walt SE, Stott S. Deficits in upper-limb task performance in children with hemiplegic cerebral palsy as defined by 3-dimensional kinematics. *Archives of Physical and Medical Rehabilitation* 2006;87(2):207-15.
121. Damiano D, Gilgannon MD, Abel M. Responsiveness and uniqueness of the Pediatric Outcomes Data Collection Instrument compared to the Gross Motor Function Measure for measuring orthopaedic and neurosurgical outcomes in cerebral palsy. *Journal of Pediatric Orthopaedics* 2005;25(5):641-45.
122. Beckung E, Hagberg G. Neuroimpairments, activity limitations, and participation restrictions in children with cerebral palsy. *Developmental Medicine & Child Neurology* 2002;44(5):309-16.
123. Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. Development and reliability of a system to classify gross motor function in children with cerebral palsy *Developmental Medicine & Child Neurology* 1997;39(4):214-23.
124. Whittle MW. *Gait analysis - an introduction*. 4th Edition ed. Oxford: Elsevier, 2007.

University of Cape Town

125. Winters TF, Gage JR, Hicks R. Gait patterns in spastic hemiplegia in children and young adults. *Journal of Bone and Joint Surgery* 1987;69(8):437-41.
126. Riad J, Haglund-Akerlind Y, Miller F. Classificaton of spastic hemiplegic cerebral palsy in children *Journal of Pediatric Orthopedics* 2007;27(7):758-64.
127. Stackhouse C, Shewokis PA, Pierce SR, Smith B, McCarthy J, Tucker C. Gait initiation in children with cerebral palsy. *Gait & Posture* 2007;26(2):301-08.
128. Imms C, Reilly S, Carlin J, Dodd K. Diversity of participation in children with cerebral palsy. *Developmental Medicine & Child Neurology* 2008;50(5):363-69.
129. Colver A. What are we trying to do for disabled children? *Current Paediatrics* 2006;16(7):501-05.
130. Sugden D, Dunford C. Intervention and the role of theory, empiricism and experience in children with motor impairment. *Disability and Rehabilitation* 2007;29(1):3-11.
131. Schmidt RA. Motor learning principles for physical therapy. In: Lister MJ, editor. *Contemporary management of motor control problems: proceedings of the II STEP conference.* Alexandria: Foundation for Physical Therapy 1991:49-63.
132. Ketelaar M, Vermeer A, Hart H, Petegem-van Beek E, Helders P. Effects of a functional therapy program on motor abilities of children with cerebral palsy. *Physical Therapy* 2001;81(9):1534-45.
133. Vandermeeren Y, Davare M, Duque J, Olivier E. Reorganization of cortical hand representation in congenital hemiplegia. *European Journal of Neuroscience* 2009;29(4):845-54.
134. Woollacott MH, Shumway-Cook A. Changes in posture control across the life span - a systems approach. *Physical Therapy* 1990;70(12):799-807.
135. Hirabayashi S, Iwasaki Y. Developmental perspective of sensory organization on postural control. *Brain and Development* 1995;17(2):111-13.
136. Peterson ML, Christou E, Rosengren KS. Children achieve adult-like sensory integration during stance at 12-years-old. *Gait & Posture* 2006;23(4):455-63.
137. Law LSH, Webb CY. Gait adaptation of children with cerebral palsy compared with control children when stepping over an obstacle. *Developmental Medicine & Child Neurology* 2005;47(5):321-28.
138. Van der Heide JC, Hadders-Algra M. Postural muscle dyscoordination in children with cerebral palsy. *Neural Plasticity* 2005;12(2-3):197-203.
139. Hadders-Algra M, van der Fits IBM, Stremmelaar EF, Touwen BCL. Development of postural adjustments during reaching in infants with CP. *Develomental Medicine & Child Neurology* 1999;41:766-76.
140. Burtner PA, Qualls C, Woollacott MH. Muscle activation characteristics of stance balance control in children with spastic cerebral palsy. *Gait and Posture* 1998;8(3):163-74.
141. Liao HF, Hwang AW. Relations of balance function and gross motor ability for children with cerebral palsy. *Perceptual and Motor Skills* 2003;96(3 pt 2):1173-84.

University of Cape Town

142. Spinazzola L, Cubelli R, Della Sala S. Impairments of trunk movements following left or right hemipshere lesions: dissociation between apraxic errors and postural instability. *Brain* 2003;126(12):2656-66.
143. Lennon S. Gait re-education based on the Bobath concept in two patients with hemiplegia following stroke. *Physical Therapy* 2001;81(3):924-35.
144. Prosser LA, Lee SCK, Barbe MF, VanSant AF, Lauer RT. Trunk and hip muscle activity in early walkers with and without cerebral palsy - A frequency analysis. *Journal of Electromyography and Kinesiology* 2010;20(5):851-59.
145. Allum JHJ, Bloem BR, Carpenter MGH, M, Hadders-Algra M. Proprioceptive control of posture: a review of new concepts. *Gait & Posture* 1998;8(3):214-42.
146. Bertenthal B, Von Hofsten C. Eye, head and trunk control: the foundation for manual development. *Neuroscience and Biobehavioral Reviews* 1998;22(4):515-20.
147. Charles J, Gordon AM. A critical review of constraint-induced movement therapy and forced use in children with hemiplegia. *Neural Plasticity* 2005;12(2-3):245-61.
148. Sveistrup H, Schneiberg S, McKinley PA, McFadyen BJ, Levin MF. Head, arm and trunk coordination during reaching in children. *Experimental Brain Research* 2008;188(2):237-47.
149. Rosenbaum PL, Walter SD, Hanna SE, Palisano RJ, Russell DJ, Raina P, et al. Prognosis for gross motor function in cerebral palsy - creation of motor development curves. *Journal of the American Medical Association* 2002;288(11):1357-63.
150. Levitt S. *Treatment of cerebral palsy and motor delay*. 5th ed. Chichester, UK: John Wiley and Sons, 2010.
151. Ketelaar M, Vermeer A, Hart H, van Petegem-van Beek E, Helders P. Effects of a functional therapy program on motor abilities of children with cerebral palsy. *Physical Therapy* 2001;81(9):1534-45.
152. van Hofsten C. An action perspective on motor development. *TRENDS in Cognitive Sciences* 2004;8(6):266-72.
153. Hadders-Algra M. Development of postural control during the first 18 months of life. *Neural Plasticity* 2005;12(2-3):99-108.
154. Berrigan F, Simoneau M, Martin O, Teasdale N. Coordination between posture and movement: interaction between postural and accuracy constraints. *Experimental Brain Research* 2006;170(2):255-64.
155. Kinney LaPier TL, Bain C, Moses S, Dunkle SE. Balance training through ball throwing activities: a research-based rationale. *Physical and Occupational Therapy in Geriatrics* 1996;14(3):23-40.
156. Geiger RA, Allen JB, O'Keefe J, Hicks RR. Balance and mobility following stroke: effects of physical therapy interventions with and without biofeedback/forceplate training. *Physical Therapy* 2001;81(4):995-1005.
157. Hartveld A, Hegarty JR. Augmented feedback and physiotherapy practice. *Physiotherapy* 1996;82(8):480-90.

University of Cape Town

158. Veličković TD, Veličković Perat M. Basic Principles of the Neurodevelopmental Treatment. *Medicina* 2005;42(41):112-20.
159. Sheppard L, Mudie H, Froude E. An investigation of bilateral isokinematic training and neurodevelopmental therapy in improving use of the affected hand in children with hemiplegia. *Physical and Occupational Therapy in Pediatrics* 2007;27(1):5-25.
160. Anttila H, Autti-Rämö I, Suoranta J, Mäkelä M, Malmivaara A. Effectiveness of physical therapy interventions for children with cerebral palsy: A systematic review *BioMed Central Paediatrics* 2008;8(14):1-10.
161. Sterba J, Rogers B, France A, Vokes D. Horseback riding in children with cerebral palsy: effect on gross motor function. *Develomental Medicine & Child Neurology* 2002;44(5):301-08.
162. Shurtleff TL, Standeven JW, Engsberg JR. Changes in dynamic trunk/head stability and functional reach after hippotherapy. *Archives of Physical and Medical Rehabilitation* 2009;90(7):1185-95.
163. Casady RL, Nichols-Larsen DS. The effect of hippotherapy on ten children with cerebral palsy. *Pediatric Physical Therapy* 2004;16(3):165-72.
164. McGibbon NH, Andrade C-K, Widener G, Cintas HL. Effect of an equine-movement therapy program on gait, energy expenditure, and motor function in children with spastic cerebral palsy: a pilot study. *Develomental Medicine & Child Neurology* 1998;40(11):754-62.
165. Sterba JA. Does horseback riding therapy or therapist-directed hippotherapy rehabilitate children with cerebal palsy? . *Develomental Medicine & Child Neurology* 2007;49(1):68-73.
166. Tech gadgets. In: Agarwal R, editor. *http://www.techgadgets.in/images/nintendo-wii-fit-us.jpg*. Mumbai, cited 24.10.2010.
167. Batavia M, Gianutsos G, Vaccaro A, Gold JT. A do-it-yourself membrane-activated auditory feedback device for weight bearing and gait training: a case report. *Archives of Physical and Medical Rehabilitation* 2001;82(4):541-45.
168. Seeger BR, Caudrey DJ, Scholes JR. Biofeedback therapy to achieve symmetrical gait in hemiplegic cerebral palsied children. *Archives of Physical and Medical Rehabilitation* 1981;62(8):364-68.
169. Donker SF, Ledebt A, Roerdink M, Savelsbergh GJP, Beek PJ. Children with cerebral palsy exhibit greater and more regular postural sway than typically developing children. *Expermintel Brain Research* 2008;184(3):363-70.
170. Flynn S, Palma P, Bender A. Feasibility of using the Sony PlayStation 2 gaming platform for an individual poststroke: a case report. *Journal of Neurologic Physical Therapy* 2007;31(4):180-89.
171. Deutsch JE, Borberly M, Filler J, Huhn K, Guarrera-Bowlby P. Use of a low-cost, commercially available gaming console (Wii) for rehabilitaton of an adolescent with cerebral palsy. *Physical Therapy* 2008;88(10):1196-207.
172. You SH, Jang SH, Kim Y-H, Kwon Y-H, Barrow I, Hallett M. Cortical reorganization induced by virtual reality therapy in a child with

University of Cape Town

hemiparetic cerebral palsy. *Develomental Medicine & Child Neurology* 2005;47(9):628-35.
173. Nitz J, Kuys S, Fu S. Is the Wii-Fit a new-generation tool for improving balance, health and well-being? A pilot study. *Climacteric* 2009;13(5):487-91.
174. Sveistrup H. Motor rehabilitation using virtual reality. *Journal of NeuroEngineering and Rehabilitation* 2004;1(10):1-8.
175. Murphy NA, Carbone PS. Promoting the participation of children with disabilities in sports, recreation, and physical activities. *Pediatrics* 2008;121(5):1057-61.
176. Holden MK, Todorov E. Chapter 49: use of virtual environments in motor learning and rehabilitation. In: Stanney K, editor. *Handbook of Virtual Environments: Design, Implementation and Applications*: Lawrence Elbraum Associates, 2002.
177. Bower E, McLellan DL. Effect of increased exposure to physiotherapy on skill acquisition of children with cerebral palsy. *Develomental Medicine & Child Neurology* 1992;34(1):25-39.
178. Trahan J, Malouin F. Intermittent intensive physiotherapy in children with cerebral palsy: a pilot study. *Develomental Medicine & Child Neurology* 2002;44(4):233-39.
179. Gagliardi C, Maghini C, Germiniasi C, Stefanoni G, Molteni F, Burt M, et al. The effect of frequency of cerebral palsy treatment: a matched-pair pilot study. *Paediatric Neurology* 2008;39(5):335-40.
180. Sullivan KJ, Kantak SS, Burtner PA. Motor learning in children: feedback effects on skill acquisition *Physical Therapy* 2008;88(6):720-32.
181. fosfor gadgets. *http://gadgets.fosfor.se/wii-fit/*, cited 14.11.2010.
182. Golafshani N. Understanding reliability and validity in qualitative research. *The Qualitative Report* 2003;8(4):597-607.
183. de Vet HCW, Bouter LM, Bezemer PD. Reproducibility and responsiveness of evaluative outcome meausures. *International Journal of Technology Assessment in Health Care* 2001;17(4):479-87.
184. Greenhalgh J, Long AF, Brettle AJ, Grant MJ. Reviewing and selecting outcome measures for use in routine practice. *Journal of Evaluation in Clinical Practice* 1998;4(4):339-50.
185. Montgomery PC, Connolly BH. Norm referenced and criterion referenced tests - use in pediatrics and application to task analysis of motor skill. *Physical Therapy* 1987;67(12):1873-76.
186. Pountney TE. *Physiotherapy for children.* illustrated ed. Philadelphia: Elsevier Ltd, 2007.
187. Atwater SW, Crowe TK, Deitz JC, Richardson PK. Interrater and test-retest reliability of two pediatric balance tests. *Physical Therapy* 1990;70(2):27-35.
188. Bruininks RH, Bruininks BD. *BOT-2 Bruininks-Oseretsky Test of Motor Proficiency* 2nd ed. Circle Pines: AGS Publishing, 2005.
189. Nolan KW, Cole LL, Liptak GS. Use of botulinum toxin type A in children with cerebral palsy. *Physical Therapy* 2006;86(4):573-84.

190. Ibrahim AI, Hawamdeh ZM, Al-Qudah AA. Functional outcome of botulinum toxin injection of gastrocnemius and adductors in spastic hemiplegic cerebral palsied children. *Europa Medicophysica* 2006;43(1):13-20.
191. Ansari NN, Naghdi S, Moammeri H, Jalaie S. Ashworth scales are unreliable for the assessment of muscle spasticity. *Physiotherapy Theory and Practice* 2006;22(3):119-25.
192. Klingels K, De Cock P, Molenaers G, Desloovere K, Huenaerts C, Jaspers E, et al. Upper limb motor and sensory impairments in children with hemiplegic cerebral palsy. Can they be measured reliably? *Disability & Rehabilitation* 2010;32(5):409-16.
193. Naghdi S, Ansari NN, Mansouri K, Asgari A, Olyaei GR, Kazemnejad A. Neurophysiological examination of the Modified Modified Ashworth Scale (MMAS) in patients with wrist flexor spasticity after stroke. *Electromyography and Clinical Neurophysiology* 2008;48(1):35-41.
194. Naghdi S, Ansari NN, Azarnia S, Kazemnejad A. Interrater reliability of the Modified Modified Ashworth Scale (MMAS) for patients with wrist flexor muscle spasticity *Physiotherapy Theory and Practice* 2008;24(5):372-79.
195. Haugh AB, Pandyan AD, Johnson GR. A systematic review of the Tardieu Scale for the measurement of spasticity. *Disability and Rehabilitation* 2006;28(15):899-907.
196. Clarkson HM, Hurabielle J. *Joint motion and function assessment: a research-based practical guide*. illustrated ed: Lippincott Williams & Wilkins, 2006.
197. Mutlu A, Livanelioglu A, Gunel MK. Reliability of goniometric measurements in children with spastic cerebral palsy. *Medical Science Monitor* 2007;13(7):323-29.
198. Gajdosik RL, Bohannon RW. Clinical measurement of range of motion. Review of goniometry emphasizing reliability and validity. *Physical Therapy* 1987;67(12):1867-72.
199. Allington NJ, Leroy N, Doneux C. Ankle joing range of motion measurements in spastic cerebral palsy children: intraobserver and interobserver reliability and reproducibility of goniometry and visual estimation. *Journal of Pediatric Orthopaedics* 2002;11(3):236-39.
200. McWhirk LB, Glanzman AM. Within-session inter-rater reliability of goniometric measures in patients with spastic cerebral palsy. *Pediatric Physical Therapy* 2006;18(4):262-65.
201. Nichols DS. Balance retraining after stroke using force platform biofeedback. *Physical Therapy* 1997;77(5):553-58.
202. Yavuzer G, Filiz E, Karakus D, Karaoglan B, Stam HJ. The effects of balance training on gait late after stroke: a randomized controlled trial. *Clinical Rehabilitation*, 2006:960-69.
203. Barclay-Goddard R, Stevenson T, Poluha W, Moffatt ME, Taback SP. Force platform feedback for standing balance training after stroke. *Cochrane Database Systematic Review*, 2004.
204. Clark RA, Bryant AL, Yonghao P, McCrory P, Bennell K, Hunt M. Validity and reliability of the Nintendo Wii balance board for assessment of standing balance. *Gait & Posture* 2009;31(3):307-10.

205. Gras LZ, Hummer D, Hine ER. Reliability and validity of the Nintendo Wii Fit. *Journal of CyberTherapy & Rehabilitation* 2009;2(4):329-35.
206. Gan SM, Tung LC, Tang YH, Wang CH. Psychometric properties of functional balance assessment in children with cerebral palsy. *Neurorehabilitation and Neural Repair* 2008;22(6):745-53.
207. Damiano D, Abel M. Relation of gait analysis to gross motor function in cerebral palsy. *Developmental Medicine & Child Neurology* 1996;38(5):389-96.
208. Palisano RJ, Hanna SE, Rosenbaum PL, Russell DJ, Walter SD, Wood E, et al. Validation of a Model of Gross Motor Function for Children with Cerebral Palsy. *Physical Therapy* 2000;80(10):974-85.
209. Russell DJ, Gorter JW. Assessing functional differences in gross motor skills in children with cerebral palsy who use an ambulatory aid or orthoses: can the GMFM-88 help? *Developmental Medicine & Child Neurology* 2005;47:462-67.
210. Moore AP, Ade-Hall RA, Tudu Smith C, Rosenbloom L, Walsh HPJ, Mohamed K, et al. Two-year placebo controlled trial of botulinum toxin A for leg spasticity in cerebral palsy. *Neurology* 2008;71(2):122-28.
211. McLaughling J, Bjornson K, Astley S, Graubert C, Hays R, Roberts T, et al. Selective dorsal rhizotomy: efficacy and safety in an investigator-masked randomized clinical trial. *Develomental Medicine & Child Neurology* 1998;40:220-32.
212. Buckon CE, Sienko Thomas S, Piatt JH, Aiona MD, Sussman MD. Selective dorsal rhizotomy versus orthopedic surgery:a multidimensional assessment of outcome efficacy *Archives of Physical and Medical Rehabilitation* 2004;85(3):457-65.
213. Reid DT, Boschen K, Wright V. Critique of the Pediatric Evaluation of Disability Inventory. *Physical and Occupational Therapy in Pediatrics* 1993;13(4):57-87.
214. Deitz JC, Kartin D, Kopp K. Review of the Bruininks-Oseretsky Test of Motor Proficiency, second edition (BOT-2). *Physical and Occupational Therapy in Pediatrics* 2007;27(4):87-102.
215. Golz A, Angel-Yeger B, Parush S. Evaluation of balance disturbances in children with middle ear effusion. *International Journal of Pediatric Otorhinolaryngology* 1998;43(1):21-26.
216. Eiser C, Morse R. The measurement of quality of life in children: past and future perspectives. *Developmental and Behavioral Pediatrics* 2001;22(4):248-56.
217. Russo RN, Goodwin EM, Miller MD, Haan EA, Connell TM, Crotty M. Self-Esteem, self-concept and quality of life in children with hemiplegic cerebral palsy. *Journal of Pediatrics* 2008;153(4):473-7.
218. Louwagie GM, Bachmann MO, Meyer K, Booysen FlR, Fairall LR, Heunis C. Highly active antiretroviral treatment and health related quality of life in South African adults with human immunodeficiency virus infection: A cross-sectional analytical study. *BioMed Central Public Health* 2007;7(244):1-10.

University of Cape Town

219. McPhail S, Beller E, Haines T. Two perspectives of proxy reporting of Health-Related Quality of Life using the Euroqol-5D, an investigation of agreement. *Medical Care* 2008;46(11):1140-48.
220. Chang PC, Yeh CH. Agreement between child self-report and parent proxy-report to evaluate quality of life in children with cancer. *Psycho-Oncology* 2005;14(2):125-34.
221. Jelsma J, Ramma L. How do children at special schools and their parents perceive their HRQoL compared to children at open schools? *Health and Quality of Life Outcomes*, 2010:1-7.
222. Stolk EA, Busschbach JJV, Vogels T. Performance of the EuroQol in children with imperforate anus. *Quality of Life Research* 2000;9(1):29-38.
223. Riley AW. Evidence that school-age children can self-report on their health. *Ambulatory Pediatrics* 2004;4(4):371-76.
224. Kaptchuk TJ. The double-blind, randomized, placebo-controlled trial: gold standard or golden calf? . *Journal of Clinical Epidemiology* 2001;54(6):541-49.
225. Freedman KB, Bernstein J. Sample size and statistical power in clinical orthopaedic research. *Journal of Bone and Joint Surgery* 1999;81-A(10):1454-60.
226. Freedman KB, Bernstein J. Sample size and statistical power of randomised, controlled trials in orthopaedics. *Journal of Bone and Joint Surgery* 2001;83-B(3):397-402.
227. Bobrovitz CD, Ottenbacher KJ. Comparison of visual inspection and statistical analysis of single-subject data in rehabilitation research. *American Journal of Physical and Medical Rehabilitation* 1998;77(2):94-102.
228. Nimon K, Williams C. Evaluating performance improvement through repeated measures: a primer for educators considering univariate and multivariate designs. *Research in Higher Education Journal*, 2009:1-20.
229. Wolery M, Harris SR. Interpreting results of single-subject research designs. *Physical Therapy* 1982;62(4):445-52.
230. Aldridge D. Single case research designs for the clinician. *Journal of the Royal Society of Medicine* 1991;84(5):249-52.
231. Harbst KB. Interrater reliability of therapists' judgments of graphed data. *Physical Therapy* 1991;71(2):32-40.
232. Parker RI, Hagan-Burke S. Useful effect size interpretations for single case research. *Behavior Therapy* 2007;38(1):95-105.
233. Nourbakhsh MR, Ottenbacher KJ. The statistical analysis of single-subject data: a comparative examination. *Physical Therapy* 1994;74(8):80-88.
234. Bulte I, Onghena P. An R package for single-case randomization tests. *Behavior Research Methods* 2008;40(2):467-78.
235. Campbell JM. Statistical comparison of four effect sizes for single-subject designs. *Behavior Modification* 2004;28(2):234-46.
236. Flanagan A, Krzak J, Peer M, Johnson P, Urban M. Evaluation of short-term intensive orthotic garment use in children who have cerebral palsy. *Pediatric Physical Therapy* 2009;21(2):201-04.

University of Cape Town

237. Gordon AM, Schneider JA, Chinnan A, Charles JR. Efficacy of a hand-arm bimanual intensive therapy (HABIT) in children with hemiplegic cerebral palsy: a randomized control trial. *Developmental Medicine & Child Neurology* 2007;49(11):830-38.
238. Yang TF, Fu CP, Kao NT, C CR, Chen SJ. Effect of botulinum toxin type A on cerebral palsy with upper limb spasticity. *American Journal of Physical Medicine and Rehabilitation* 2003;82(4):284-89.
239. Yam WKL, Leung MSM. Interrater reliability of Modified Ashworth Scale and Modified Tardieu Scale in children with spastic cerebral palsy. *Journal of Child Neurology* 2006;21(12):1031-35.
240. Pandyan AD, Johnson GR, Price CIM, Curless RH, Barnes MP, Rodgers H. A review of the properties and limitations of the Ashworth and modified Ashworth Scales as measures of spasticity. *Clinical Rehabilitation* 1999;13(5):373-83.
241. Statistica 8 [program]. Tulsa, Oklahoma: Statsoft, 2009.
242. NCSS - Statistical & Power Analysis Software. Kaysville, Utah, 2010.
243. Singh R, Bhalla A, Lehl S, Sachdev A. Video game epilepsy. *Neurology India* 2001;49(4):411-12.
244. Chuang YC, Chang W, Lin TK, Lu CH, Chen SD, Huang CR. Game-related seizures presenting with two types of clinical features. *Seizure* 2006;15(2):98-105.
245. Ferrie CD, Marco PD, Grünewald RA, Giannakodimos S, Panayiotopoulos C. Video game seizures. *Journal of Neurology, Neurosurgery & Psychiatry* 1994;57(8):925-31.
246. World Medical Association Declaration of Helsinki. *http://www.cgmh.org.tw/intr/intr1/c0040/web/C/Declaration%20of%20Helsinki.pdf.*, cited 01.05.2009.
247. Chung CY, Lee SH, Choi IH, Cho T-J, Yoo WJ, Park M. Residual pelvic rotation after single-event multilevel surgery in spastic hemiplegia. *Journal of Bone and Joint Surgery* 2008;90(9):1234-8.
248. Wanigasinghe J, Reid SM, Mackay MT, Reddihough DS, Harvey AS, Freeman JL. Epilepsy in hemiplegic cerebral palsy due to perinatal arterial ischaemic stroke. *Develomental Medicine & Child Neurology*, 2010.
249. Hartveld A, Hegarty JR. Frequent weightshift practice with computerised feedback by cerebral palsied children - four single-case experiments. *Physiotherapy* 1996;82(10):573-80.
250. Brady K, Garcia T. Constraint-Induced movement therapy (CIMT): pediatric applications. *Developmental Disabilities Research Reviews* 2009;15(2):102-11.
251. Horak FB, Henry SM, Shumway-Cook A. Postural perturbations: new insights for treatment of balance disorders. *Physical Therapy* 1997;77(5):517-33.
252. Liao HF, Jeng SF, Lai J-S, Cheng C-K, Hu M-H. The relation between standing balance and walking function in childern with spastic diplegic cerebral palsy. *Develomental Medicine & Child Neurology* 1997;39(2):106-12.
253. Viau A, Feldman AG, McFadyen BJ, Levin MF. Reaching in reality and virtual reality: a comparison of movement kinematics in healthy subjects

University of Cape Town

and in adults with hemiparesis. *Journal of NeuroEngineering and Rehabilitation* 2004;1(11):1-7.
254. Gorter H, Holty L, Rameckers EE, Elvers HJ, Oostendorp R. Changes in endurance and walking ability through functional physical training in children with cerebral palsy. *Pediatric Physical Therapy* 2009;21(1):31-37.
255. Bengtsson M, Ohlsson B, Ulander K. Development and psychometric testing of the Visual Analogue Scale for Irritable Bowel Syndrome. *BioMed Central Paediatrics* 2007;7(16):1-10.
256. Hartmannsgruber MWB, Swamidoss CP, Budde A, Qadir S, Brull SJ, Silvermann DG. A method of overcoming the ceiling effect of bounded pain scales. *Journal of Clinical Monitoring and Computing* 1999;15:455-59.
257. Kimman ML, Dirksen CD, Lambin P, Boersma LJ. Responsiveness of the EQ-5D in breast cancer patients in their first year after treatment. *Health and Quality of Life Outcomes* 2009;7(11):1-7.
258. Deutsch JE, Robbins D, Morrison J, Guarrera-Bowlby P. Wii-based compared to standard of care balance and mobility rehabilitation for two individuals post-stroke. *Virtual Rehabilitation International Conference*, 2009.
259. Bar-Haim S, Harries N, Nammourah I, Oraibi S, Malhees W, Loeppky J, et al. Effectiveness of motor learning coaching in children with cerebral palsy: a randomized controlled trial. *Clinical Rehabilitation* 2010;24(11):1009-20.
260. Christiansen AS, Lange C. Intermittent versus continuous physiotherapy in children with cerebral palsy. *Develomental Medicine & Child Neurology* 2008;50(4):290-93.
261. Sorsdahl AB, Moe-Nilssen R, Kaale HK, Rieber J, Strand LI. Change in basic motor abilities, quality of movement and everyday activities following intensive, goal-directed, activity-focused physiotherapy in a group setting for children with cerebral palsy. *BioMed Central Paediatrics*, 2010:1-11.
262. Schlosser RW. The role of single-subject experimental designs in evidence-based practice times. *FOCUS - A publication of the National Center for the Dissemination of Disability Research (NCDDR)*, 2009.
263. Horner RH, Carr EG, Halle J, McGee G, Odom S, Wolery M. The use of single-subject research to identify evidence-based practice in special education. *Exceptional Children* 2005;71(2):165-79.
264. Cheng P-T, Wang C-M, Chung C-Y, Chen C-L. Effects of visual feedback rhythmic weight-shift training on hemiplegic stroke patients. *Clinical Rehabilitation* 2004;18(7):747-53.
265. Levac D, Pierrynowski MR, Canestraro M, Gurr L, Leonard L, Neeley C. Exploring children's movement characteristics during virtual reality video game play. *Human Movement Science*, 2010.
266. Kanda T, Pidcock FS, Hayakawa K, Yamori Y, Shikata Y. Motor outcome differences between two groups of children with spastic diplegia who received different intensities of early onset physiotherapy followed for 5 years. *Brain Development* 2004;26(2):118-26.
267. Arpino C. Efficacy of intensive versus nonintensive physiotherapy in children with cerebral palsy: a meta-analysis. *International Journal of Rehabilitation Research* 2010;33(2):165-71.

268. Kwakkel G, Wagenaar RC, Twisk JWR, Lankhorst GJ, Koetsier JC. Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. *The Lancet* 1999;354(9174):191-96.
269. Van Peppen RPS, Kwakkel G, Wood-Duaphinee S, Hendriks EJM, Van der Wees PJ, Dekker J. The impact of physiotherapy on functional outcome after stroke: What's the evidence? *Clinical Rehabilitation* 2004;18(8):833-62.
270. Chiodo LK, Gerety MB, Mulrow CD, Rhodes MC, Tuley MR. The impact of physical therapy on nursing home patients outcomes. *Physical Therapy* 1992;72(3):173-75.
271. Jette DU, Warren RL, Wirtalla C. The relation between therapy intensity and outcomes of rehabilitation in skilled nursing facilities. *Archives of Physical Medicine and Rehabilitation* 2005;86(3):373-79.
272. Wolery M, Busick M, Reichow B, Barton E. Comparison of overlap methods for quantitatively synthesizing single-subject data. *The Journal of Special Education* 2010;44(1):18-28.
273. Shadish WR, Rindskopf DM. Methods for evidence-based practice: quantitative synthesis of single-subject designs. *New Directions for Evaluation* 2007.
274. Damiano DL, Dodd K, Taylor NF. Should we be testing and training muscle strength in cerebral palsy? *Develomental Medicine & Child Neurology* 2002;44(1):68-72.
275. Telework and people with disabilities. *http://www.eto.org.uk/twork/disindex.htm:* European Telework Online, cited 09.10.2010.
276. Freeman M. *Physical Therapy of Cerebral Palsy*. New York: Springer, 2007.
277. Bober T, Dziuba A, Krystyna K-B, Kulig K. Gait characteristics following achilles tendon elongation: the foot rocker perspective. *Acta of Bioengineering and Biomechanics* 2008;10(1):37-42.
278. Gordon AB, Baird GO, McMulkin ML, Caskey PM, Ferguson RL. Gait analysis outcomes of percutaneous medial hamstring tenotomies in children with cerebral palsy. *Journal of Pediatric Orthopaedics* 2008;28(3):324-29.
279. Dietz FR, Albright JC, Dolan LD. Medium term follow-up of achilles tendon lengthening in the treatment of ankle equinus in cerebral palsy. *Iowa Orthopedic Journal* 2006;26:26-27.
280. Borton DC, Walker K, Pirpiris M, Nattrass GR, Graham HK. Isolated calf lengthening in cerebral palsy: outcome analysis of risk factors. *Journal of Bone and Joint Surgery* 2001;83(3):364-70.
281. Kondo I, Hosokawa K, Iwata M, Oda A, Nomura T, Ikeda K, et al. Effectiveness of selective muscle-release surgery for children with cerebral palsy: longitudinal and stratified analysis. *Develomental Medicine & Child Neurology* 2004;46(8):540-47.
282. Graham HK, Selber P. Musculoskeletal aspects of cerebral palsy. *Journal of Bone and Joint Surgery* 2003;85-B(2):157-66.
283. Tedrof K. Children with spastic cerebral palsy: aspects of muscle activity and botulinum toxin A treatment. Karolinska Institutet, Stockholm, Sweden, 2009.

University of Cape Town

284. Lukban MB, Rosales RL, Dressler D. Effectiveness of botulinum toxin A for upper and lower limb spasticity in children with cerebral palsy: a summary of evidence. *Journal of Neural Transmission* 2009;116(3):319-31.
285. Rameckers EA, Speth LA, Duysens J, Vles JS, Smits-Engelsman B. Botulinum toxin-A in children with congenital spastic hemiplegia does not improve upper extremity motor-related function over rehabilitation alone: a randomized controlled trial. *Neurorehabilitation and Neural Repair* 2009;23(3):218-25.
286. Wasiak J, Hoare B, Wallen M. Botulinum toxin A as an adjunct to treatment in the management of the upper limb in children with spastic cerebral palsy. *Cochrane Database Systematic Review*, 2004.
287. Autti-Rämö I, Suoranta J, Anttila H, Malmivaara A, Mäkelä M. Effectiveness of upper and lower limb casting and orthoses in children with cerebral palsy. *American Journal of Physical Medicine & Rehabilitation* 2006;85(1):89-103.
288. McNee AE, Will E, Lin JP, Eve LC, Gough M, Morrissey MC, et al. The effect of serial casting on gait in children with cerebral palsy: preliminary results from a crossover trial. *Gait & Posture* 2007;25(463-468).
289. Lannin NA, Novak I, Cusick A. A systematic review of upper extremity casting for children and adults with cerebral nervous system motor disorders. *Clinical Rehabilitation* 2007;21(11):963-76.
290. Rodda J, Graham HK. Classification of gait patterns in spastic hemiplegia and spastic diplegia: a basis for a management algorithm. *European Journal of Neurology* 2001;8(5):98-108.
291. Radtka SA, Skinner SR, Dixon DM, Johanson ME. A comparison of gait with solid, dynamic and no ankle-foot orthoses in children with spastic cerebral palsy. *Physical Therapy* 1997;77(4):395-409.
292. Balaban B, Yasar E, Dal U, Yazicioglu K, Mohur H, Kalyon T. The effect of hinged ankle-foot orthosis on gait and energy expenditure in spastic hemipelgic cerebral palsy. *Disability and Rehabilitation* 2007;29(2):139-44.
293. Blackmore AM, Garbellini SA, Buttigieg P, Wells J. A systematic review of the effects of soft splinting on upper limb function in people with cerebral palsy. *American Academy for Cerebral Palsy and Developmental Medicine*, 2006:1-22.
294. Damiano D, Abel MF. Functional outcomes of strength training in spastic cerebral palsy. *Archives of Physical and Medical Rehabilitation* 1998;79(2):119-1125.
295. Scholtes VA, Dallmeijer AJ, Rameckers EA, Verschuren O, Tempelaars E, Hensen M, et al. Lower limb strength training in children with cerebral palsy - a randomized controlled trial protocol for functional strength training based on progressive resistance exercise principles. *BioMed Central Paediatrics* 2008;8(41):1-11.
296. GMFM Score Sheets. http://motorgrowth.canchild.ca/en/GMFM/gmfmscoresheets.asp. Hamilton, Ontario: McMaster University - CanChild Centre for Childhood Disability Research, cited 10.05.2009.

University of Cape Town

297. Bohannon RW, Smith MB. Interrater Reliability of a Modified Ashworth Scale of Muscle Spasticity. *Physical Therapy* 1987;67(2).
298. EQ-5D. *http://www.euroqol.org/*. Rotterdam, Netherlands: EuroQol Group, cited 05.05.2009.

University of Cape Town

8. Appendices

8.1 Surgical and Non-surgical treatment for children with spastic hemiplegic cerebral palsy

8.2 Parent Information leaflet and Consent Form

8.3 Child Information leaflet and Consent Form

8.4 Weekly data collection sheet

8.5 Individual Log Sheet of Gaming

8.6 Chi-Square Tables

8.7 GMFM Scoring Sheet

8.8 Original BOT-2 Subtest 5: Balance and Subtest 6: Running Speed and Agility

8.9 The Modified Ashworth Scale

8.10 The EQ-5D-Y VAS

University of Cape Town

University of Cape Town

8.1 Surgical and non-surgical treatment of children with spastic hemiplegic cerebral palsy

There are a number of interventions commonly enlisted in the treatment of children with spastic hemiplegic cerebral palsy. The surgical treatments may be classified as temporary or permanent and as focal or generalised.

8.1.1 Tenotomies

The surgical release of a tendon is referred to as a tenotomy. Tenotomies are commonly carried out in upper and lower limb deformities where shortening of the musculotendinous unit prohibits conventional range of movement. Common upper limb deformities that are surgically treated include elbow flexion contractures, forearm pronation, wrist flexion and ulnar deviation, thumb in palm and swan-neck deformities in the digits. In the upper limb, surgery is generally used to improve cosmetic appearance and hand function [276]. In the lower limb, a common surgical intervention is the elongation of the Tendon Achilles (ETA) [277]. This is used to correct equinus deformities at the ankle [277] . Hamstring tenotomies may be used to correct knee flexion contractures [278]. The goal of these procedures is to provide sufficient plantarflexor range to allow a conventional 'heel to toe' progression with sufficient dorsiflexion during the gait cycle as well as increased knee extension at initial contact [277 278]. The Achilles tendon should not be lengthened excessively however, because this results in the disruption of the propulsive activity of the plantarflexors [277]. There are a number of different surgical techniques used to lengthen the tendon Achilles. These include open or closed percutaneous procedures, coronal Z-lengthening and sagittal Z-lengthening [279]. In some instances only the Gastrocnemius tendon is lengthened as opposed to the entire Achilles tendon [279]. Gastrocnemius lengthening alone allows for the maintenance of propulsion during toe-off [279]. It is however associated with an increased rate of recurrent deformity [279]. Lengthening the entire Achilles tendon is associated with less recurrence of deformity but a greater chance of over-lengthening [279]. The correct choice of technique for a given patient is controversial [279] and techniques are often chosen on the

University of Cape Town

basis of the skill of the surgeon. The degree of lengthening is determined by the amount of dorsiflexion range achieved during surgery [279]. The tendon is then sutured after lengthening [279]. Tendon lengthening procedures may be following by a recurrent equinus in approximately 10-30% of cases [280]. Significant gains in gross motor function have been found following tendon release procedures of the lower limb [281].

8.1.2 Selective Dorsal Rhizotomies

Selective dorsal rhizotomy (SDR) is a neurosurgical method to manage generalised spasticity of the lower limbs [282]. This type of surgery has a permanent effect in reducing spasticity [283]. A laminoplasty is performed in the lumbar spine from L1 to S1 and then 20-40% of the dorsal rootlets which make up the L1 to S1 posterior nerve roots are cut [282]. The laminae are then replaced to prevent deformity of the spine [282]. Spasticity is markedly reduced following this type of surgery but is accompanied by weakness in the lower limb [282]. An intensive physiotherapy regime is required to regain muscle strength and function [282]. The reduction in spasticity allows for greater joint ranges in the lower limb and results in a positive effect on mobility and gait function [282]. Improvements that have been reported following SDR include increased walking speed, increased stride length, a reduction in dynamic equinous, increased hip, knee and ankle range of movement and a reduction in energy expenditure during walking [282].

University of Cape Town

8.1.3 Botox

Botox injections are intramuscular injections of phenol and BTX-A [282]. Phenol is a neurolytic agent [282]. The BTX-A is a powerful neurotoxic substance produced by the Clostridium botulinum bacterium [282]. BTX-A attaches itself to cholinergic nerve endings and blocks the release of acetylcholine [282]. The body responds to this by sprouting new nerve endings in an effort to restore neurotransmission [282]. This process takes about 3 months [282]. As a result, the effects of botox are completely reversible and are dose-dependent [282]. The aim of injecting botox is to convert paresis with muscle hyperactivity to paresis with muscle hypoactivity [282]. Botox is often used in the management of

dynamic equinous deformities, adductor spasticity, and hamstring spasticity which lead to toe-walking, scissoring and crouching gait respectively [282]. The decreased muscle tone in the lower limbs leads to improved gait function [284].Upper limb spasticity may also be treated with botox injection [282]. However, studies investigating the effect of botox paired with rehabilitation opposed to rehabilitation alone have found no significant differences in the outcome of upper limb function. It was found that botox causes weakness and as a result does not necessarily aid in improving gross and fine motor function of the upper limb [285 286].

8.1.4 Casting

Casting is used to stretch muscles in the upper and lower limb for short periods of time [287]. This is done by fixing the ankle in a plantargrade or dorsiflexed position in a cast [288]. Casting in children with hemiplegic cerebral palsy is most commonly used to stretch the ankle plantarflexors with the aim of reducing the equinus deformity at the ankle [288]. Only mild fixed ankle plantarflexor contractures are usually treated with casting [288]. A minimum period of 2 weeks of permanent casting is suggested although casting may last up to 10 weeks [288]. The cast is removed and reapplied at intervals of 2-14 days and the ankle is progressively positioned in increased dorsiflexion range to stretch the calf muscle gradually [288]. The period of permanent casting may be followed by splinting or casting for shorter periods during the day [288]. Serial casting has been found to improve ankle dorsiflexion as well as stride length during the gait cycle [288]. It has however been reported that these gains following lower limb casting may only be short-lived [287]. Other studies have reported significant improvements in gait function for up to 12 months post casting [288]. The same was found for upper limb casting: when paired with physiotherapeutic or occupational therapeutic measures, upper limb casting only has short-term effects on quality and range of movement [287]. Upper limb serial casting alone has not yet been proven to be beneficial [289].

University of Cape Town

8.1.5 Ankle-Foot Orthoses

Ankle plantarflexion or 'drop foot' deformities are often treated with Ankle-Foot Orthoses [290]. These are usually made of polypropelene and cover the posterior calf and mediolateral borders and sole of the foot [291]. In this way the orthotic provides a mechanical force, counteracting the plantarflexion and resultant shortening of the Tendon Achilles caused by increased tone in the calf muscles [276 291] . Alternatively, in cases of poor selective control of the dorsiflexors, the AFO may maintain the ankle in plantargrade, preventing a drop foot during the swing phase [290]. Orthotics may be fixed or may be hinged at the ankle joint to allow dorsiflexion during gait [276]. AFO's have been shown to improve balance ability in children. Hinged AFO's seem to be particularly helpful in this manner [276]. They also improve stability during the stance phase of the gait cycle as well as improved ankle position during the swing phase and initial contact [276]. AFO's have been shown to reduce the energy expenditure required during walking [292]. As a result ankle foot orthoses are commonly prescribed for children with spastic hemiplegic cerebral palsy to improve quality and efficiency of movement.

8.1.6 Upper limb orthoses

Upper limb orthoses and splints are generally used to prevent contractures and deformity that occur as a result of muscle shortening and spasticity [276]. Splinting is based on two approaches [293]. The first is the Biomechanical approach [293]. The rationale behind this approach is to prevent deformity by mobilising and stretching soft tissue structures tend to shorten due to spasticity or increased tone in the hemiplegic upper limb [293]. The second approach is a neurophysiological approach [293]. This aims to reduce spasticity by keeping the limb in a reflex inhibiting position under sustained stretch [293]. Splints may be pliable or rigid [293]. Soft splints are made of neoprene or lycra [293]. Rigid splints may include a hinged component [293]. Wrist and hand splints as well as thumb splints are commonly used for children with hemiplegic cerebral palsy [276]. Time prescriptions vary but a minimum of 4 to 8 hours of wear a day is usually prescribed [276]. Splinting is believed to improve sensory and proprioceptive awareness, increase proximal stability and enhance hand function but evidence to support these claims is not yet available.

University of Cape Town

According to the evidence, upper limb splints rarely provide functional benefit [276]. They serve largely to prevent severe cosmetic deformity of the upper limb [276].

8.1.7 Constraint Induced Movement Therapy

The inability to effectively use the hemiplegic upper limb may lead to frustration and learned non-use whereby hand use becomes heavily biased towards the unaffected hand [6]. It is believed that this diminished use of the hemiparetic hand furthers the degradation of neuromotor pathways from the affected brain hemisphere to the hemiplegic hand [6]. The rationale for Constraint-Induced Movement Therapy is to reduce learned non-use of the hemiplegic upper limb [6]. This type of therapy involves an intensive period of massed practice over a short period of time. The patient is required to wear a restraining device (mitt, cast, splint, sling) to prevent use of the unaffected upper limb during therapy [6]. The idea is that intensive repetition of movement with the previously neglected upper limb allows for the emergence of new motor skills [6]. The active involvement of the subject is thought to stimulate re-organization of sensory and motor areas of the brain [6]. Studies have shown positive results, however, the standard therapy regimen requires practice of up to 6 hours a day for a period of 2 weeks [6]. This has been criticised due to concerns that young children cannot participate in such prolonged periods of concentration and practice [6].

University of Cape Town

8.1.8 Strength Training

Muscle paresis or weakness is a clinical characteristic of cerebral palsy [294]. Neurosurgical procedures such as dorsal rhizotomies have made it even more evident in recent years seeing as these procedures reduce spasticity and expose the underlying muscle weakness [294]. Studies investigating the effects of strength training on spastic muscles suggest beneficial effects that contradict the dated belief that strengthening increases spasticity [282]. It has been found that muscle strength can be measured reliably in children with cerebral palsy [282] and that children with cerebral palsy can improve their muscle strength at a rate similar to that of persons who have muscle weakness of non-

neurological origin [294]. Gains in strength have been reported to result in improved gross motor function [282]. Some studies have demonstrated a correlation between the muscle strength of children with cerebral palsy and their walking efficiency [20]. Knee extensor strength in particular has been found to be related to walking efficiency [20]. However, training protocols and methods vary widely [295]. As a result, the effects of strength training are still under debate.

University of Cape Town

8.2 Parent information leaflet and consent form

University of Cape Town

University of Cape Town

University of Cape Town

School of Health and Rehabilitation Sciences

Division of Physiotherapy

The effect of the Nintendo Wii Fit on the balance control and gross motor function of children with spastic hemiplegic cerebral palsy

Dear Parent

My name is Marieke Pronk. I am a Physiotherapist doing a Masters in Physiotherapy at the University of Cape Town. As a part of my Masters degree, I would like to complete some of my data collection at the school that your child is attending. I ask you kindly to consider your child's participation in this study.

University of Cape Town

Purpose of this study:

Children with cerebral palsy are known to have trouble with their balance. In addition to this, children with hemiplegia tend to put more of their body weight on their good leg when they are walking. This can make the muscles smaller and weaker on the hemiplegic side. Therefore, Physiotherapists often try to get hemiplegic children to take more weight through the hemiplegic leg and to improve their balance during treatment.

Nintendo has recently brought out a gaming console that requires the player to move around in order to play the TV game. The Nintendo Wii Fit is a balance board that consists of four force plate sensors that measure the patient's centre of gravity and weight. This information is then used in balance games such as snowboarding, skiing or heading a soccer ball while the patient stands on the balance board. The user plays the game by shifting his weight from front to back and side to side as he slides down ski slopes for example.

Hospitals and rehabilitation clinics in Germany, the UK and the USA have already started using Nintendo Wii Fit exercise sessions in the treatment of patients who have poor balance. It is possible that children with hemiplegic cerebral palsy might also benefit from such a gaming system. We would like to investigate whether using the Nintendo Wii Fit can improve symmetrical weight bearing and balance in children with hemiplegic cerebral palsy.

What would be expected from your child?

This study will be 9 weeks long and consists of a measurement phase of 6 weeks and a treatment phase of 3 weeks. In the measurement phase, the researcher will come to your child's school once a week on a Monday to do the Timed Up and Down Stairs test, The Gross Motor Function Measure Dimensions D and E and the Nintendo Wii Fit body test. These include activities such as climbing up and down a flight of stairs, standing on one leg and kicking a ball, hopping on one leg and walking backwards and forwards without support. Your child will also be asked to answer a quality of life questionnaire consisting of 6 questions. The assessment process is expected to take roughly half an hour. Your child's teacher will be asked to allocate a sensible time for your child to leave the classroom. During the measurement phase, your child will continue with their regular physiotherapy schedule.

When the treatment phase of the study begins, your child will no longer receive conventional physiotherapy. Instead, the physiotherapists at the school will play the Wii games with your child during their time slots. The treatment phase of this study is only 3 weeks long, meaning that only 6 of your child's physiotherapy sessions will be replaced with the Wii Fit games and then he/she returns back to their conventional physiotherapy routine. In these 3 weeks, we will also ask your child to come and play on the Nintendo Wii Fit during 2 break times per week. This will allow us to increase the time spent on the Nintendo Wii Fit balance games without having to use more of their class time for out study. In effect, your child will only be outside of his/her class for an additional half an hour per week for measurement purposes on a Monday over a period of 9 weeks. No additional time outside of school hours will be used for this study.

University of Cape Town

What would be expected from you?

You will be asked to sign a consent form that will allow your child to take part in this study. Your child will also be given Quality of Life questionnaires to take home. We ask you kindly to complete these questionnaires on behalf of your child, but from your point of view. Over the course of 9 weeks, you will be asked to complete 3 of these questionnaires, consisting of 6 questions each. You will be given instructions along with the questionnaire to ensure that you understand what is required from you. Parents' completion of these questionnaires will allow us to compare Health Related Quality of Life reports given by children and their parents.

How would your child benefit from taking part in this study?

Although it has not yet been proven, we expect and hope to confirm that the use of the Nintendo Wii Fit will improve the balance and symmetrical weight bearing in the children who take part in this study. Previous trials done by us have shown that children enjoy the Wii Fit games tremendously. The variation in exercise routine might be welcomed by your child. Your child will not be paid to participate in this study.

Are there any risks involved?

The fact that your child is required to be outside the classroom for half an hour more than usual, might be a cause for your concern. If you feel that your child's academic work will suffer due to this, then you are free to decline participation in this study.

If your child does take part in this study, he/she will not miss any important tests or assessments for the purpose of this study. Every effort will be made to arrange the most appropriate times for your child to leave the classroom for half an hour on a Monday. Otherwise his/her conventional physiotherapy time slots will be used over a course of three weeks for the purpose of this study.

People with epilepsy may suffer from seizures or blackouts caused by flashing lights. If your child has epilepsy or seizures, he or she will not be allowed to take part in this study. Therefore, we urge you, to inform us if your child is an epilepsy sufferer.

Children may complain of delayed onset muscle soreness or muscle ache after playing the Nintendo Wii Fit games. This is a harmless and common consequence of doing a new exercise that one has not done before. It means that your child is activating muscles that he/she might previously not have used as much. If your child gets tired during the Wii Fit sessions, he/she will be allowed to rest, drink water or have bathroom breaks.

The Nintendo Wii Fit is 5 cm in height. This means that your child will have to balance on a surface that is slightly raised above the ground. Although falls are unlikely, Physiotherapists who monitor the gaming will be asked to stay alert and prevent falls where possible. The area around the balance board will be cleared so that no serious injury can occur, should the child fall. All children who take part in this study will be covered by the UCT Group Insurance plan and will be compensated in the unlikely event of an injury.

University of Cape Town

Your child's name will not be used in conjunction with any of his/her assessment scores. Each child will be given a number for identification purposes, therefore they will remain anonymous. Your child's information and assessment sheets will be kept in an individualised folder that only the researcher will have access to.

Is there a reason why my child should not take part in this study?

If you have a Nintendo Wii Fit at home, we ask you to bring this to our attention. We will then have to exclude your child from participating in this study. Children who are accustomed to using the Wii Fit might not display any additional improvements and we will not be able to see a treatment effect.

Does your child have to take part in this study?

Your child's participation depends entirely on your consent. Your consent is voluntary. If you change your mind about your child's participation in the study, you may withdraw your consent at any time. If your child decides that he/she does no longer want to participate, then he/she is free to discontinue the study at any time. There will be no consequences to withdrawal from the study. Refusal to take part in this study will not affect the quality of education or treatment that your child will receive in future. However, we kindly ask you to consider your child's participation favorably.

If you have any questions or would like to know more about this study, please do not hesitate to call or email the researcher at:

Cell: 072 497 2260 **e-mail: prnmar011@uct.ac.za**

I hope that I will have the privilege of working with your child.
Yours sincerely,
Marieke Pronk
(BSc Physiotherapy, UCT)

Supervisor: Prof. Jennifer Jelsma
School of Health and Rehabilitation Science
Division of Physiotherapy
Faculty of Health Sciences
University of Cape Town
Anzio Road
Observatory, 7925
Tel: 27-21-4066401
Fax: 27-21-4066323

Marc Blockman
Research Ethics Committee
Faculty of Health Sciences
E 52-23 Old Main Building
Groote Schuur Hospital
Observatory 7925
Tel: +27- 21- 4066492
Fax: +27- 21- 4066411

University of Cape Town

University of Cape Town
School of Health and Rehabilitation Sciences
Division of Physiotherapy

Parent/Guardian Consent Form

This study serves to investigate the effect of a Nintendo Wii Fit intervention on the balance control of 7-14 year old independently ambulating children . By signing this form, you agree that:

- Your child may participate in this study
- Your child agrees to participate in this study
- You agree to share information regarding your child's quality of life as accurately and truthfully as possible
- Participation in this study means that your child has to miss half an hour of class on a Monday for 9 weeks in a row.
- Your child will be receiving the Nintendo Wii Fit treatment as a different form of therapy to their conventional physiotherapy for a period of 3 weeks.
- You have received an information leaflet describing the purpose and procedure of this study
- You have been given the opportunity to ask questions you might have related to the study
- You have been told that your consent for your child's participation in this study is voluntary and that you have the right to withdraw at any time without having to justify your decision to do so
- You have been told that your declining to take part in this study will not have any consequences for you or your child in the future
- You were informed that you and your child would not be paid for taking part in this study
- You were informed that data related to your child's motor function and quality of life will remain confidential
- You were informed that all parents and children will remain anonymous on publication of this study

University of Cape Town

I hereby declare that I am the child's legal guardian. I give my consent for the child in my care to take part in this study.

Signed by Parent _____ **Date:** _____

Signed by Researcher _____ **Date:** _____

Signed by Witness _____ **Date:** _____

University of Cape Town

8.3 Child information leaflet and consent form

University of Cape Town

University of Cape Town

University of Cape Town
School of Health and Rehabilitation Sciences
Division of Physiotherapy

The effect of the Nintendo Wii Fit on the balance control and gross motor function of children with spastic hemiplegic cerebral palsy

Dear _____

My name is Marieke Pronk. I am a Physiotherapist and I would like you to take part in my study.

What is this study about?
I would like to test whether we can help children with hemiplegia get better balance by letting them play on the Nintendo Wii Fit.

The Nintendo Wii Fit is a balance board that you stand on. It feels your movement and lets you play TV games like skiing, snowboarding and soccer.

What would we expect from you?
For 9 weeks, I will come to your school every Monday and ask you to join me in the physiotherapy room. This will mean that you will miss half an hour of class time on a Monday. I will arrange this time with your teacher before we start the study. In this half an hour, we will do activities such as jumping on one leg and climbing stairs so that I can test how good your balance is.

For 3 of the 9 weeks that we will be testing your balance, the physiotherapist at your school will play the Nintendo Wii Fit games with you in your physiotherapy session. This means that you will not get your conventional physiotherapy for 3 weeks. In these 3 weeks we will also ask you to come and play on the Nintendo Wii Fit in some of your break times.

Why should you think about it before you say "yes" to taking part in this study?

- You will be outside of class for half an hour every Monday. This means that you might have to catch up on the class work that you have missed.
- You will have to come and play on the Nintendo Wii Fit during some of your break times.
- Although the Nintendo Wii Fit is not difficult to play on, some people get sore muscles from doing a new exercise that they have not done before.

Do you have to take part in this study even if you do not want to?
No, you do not have to take part in this study if you do not want to. We can only let you take part if you want to and if your mother or father allow you to take part. If you decide that you do not like taking part in this study, then you can stop taking part at any time.

University of Cape Town

University of Cape Town
School of Health and Rehabilitation Sciences
Division of Physiotherapy

Child Consent Form

In this study we would like to see if we can help children with hemiplegia get better balance by letting them play on the Nintendo Wii Fit.

Please read through the following points and see if you agree with them:

- You understand what this study is about.
- You understand that you will miss half an hour of class on a Monday for 9 weeks.
- You understand that you will meet the Physiotherapist who is doing this study in the physiotherapy room every Monday to do the balance tests.
- You understand that you will be asked to play the Nintendo Wii Fit games instead of getting your conventional physiotherapy for 3 weeks.
- You understand that, in these 3 weeks you will also have to come in during some of your break times to play on the Nintendo Wii Fit.
- You understand that if you do not like taking part in this study after trying, you can tell the Physiotherapist and then you will be allowed to quit this study.

If you agree with all the points that you have just read and you would like to take part in this study, please sign your name on the first line.

University of Cape Town

Signed by Child _____ **Date:** _____

Signed by Researcher _____ **Date:** _____

Signed by Witness _____ **Date:** _____

8.4 Data collection sheets

University of Cape Town

University of Cape Town

Baseline Measures – MAS, ROM and GMFCS

Name: _____ **Date:** _____
Side of Hemiplegia: _____

Modified Ashworth Scale

Muscle	Score
Quadriceps	
Hamstrings	
Gastrocnemius	

The Modified Ashworth Scale:

0	**No increase in muscle tone**
1	**Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of range of motion (ROM) when the affected part(s) is moved in flexion or extension**
1+	**Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM**
2	**More marked increase in muscle tone through most of ROM, but affected part(s) easily moved**
3	**Considerable increase in muscle tone, passive movement difficult**
4	**Affected part(s) rigid in flexion or extension**

Quadriceps: With the patient in supine, move the knee from full extension to full flexion
Hamstrings: With the patient in supine, move the knee from full flexion to full extension
Gastrocnemius: With the patient in supine, move the ankle from full plantarflexion to full dorsiflexion (measured with the knee extended)

Speed of movement: the movement should take roughly 1 second to complete
Number of repetitions: each movement may be repeated 2 times before a score is given

University of Cape Town

ROM:

Joint and movement	R limb ROM	L limb ROM
Ankle Dorsiflexion		
Ankle Plantarflexion		
Knee flexion		
Knee extension		

GMFCS Level:

1. Have you ever used a hand-held mobility device to walk eg a crutch, cane or walker? :

Yes: _____ **No:** _____

2. Do you use a mobility device (crutch, cane, walker) or a wheelchair when you walk long distances outside?

Yes: _____ **No:** _____

3. Do you need assistance when stepping up or down a curb?

Yes: _____ **No:** _____

4. Do you have to hold onto the rail or banister when walking up and down stairs?

Yes: _____ **No:** _____

5. Do you play any kind of sport?

Yes: _____ **No:** _____

University of Cape Town

Weekly Data Collection Sheet

Date of this assessment: _____
Week: _____
Name:
Identification number:
Date of Birth:
Age:
Side of hemiparesis:
MAS score as measured in Week 1:

Triceps Surae	
Hamstrings	
Quadriceps	

ROM as measured in Week 1:

Joint	Right	Left
Ankle		
Knee		

Measurement Outcomes:

Timed Up and Down Stairs:

Time to complete in seconds: _____

Adapted BOT-2 Subtest scores:

Balance: _____

Running Speed and Agility: _____

EQ-5D-Y:

VAS score (out of a 100): _____

Additional Comments:

_____
_____
_____

University of Cape Town

Adapted Version of Subtest 5: Balance of the BOT-2

Activity	Trial 1	Trial 2							Point Score
1) Standing with feet apart on a line – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
2) Walking Forward on a line	steps	steps	Raw	0	1-2	3-4	5	6	
			Point	**0**	**1**	**2**	**3**	**4**	
3) Standing on **Unaffected Leg** on a line – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
4) Standing on **Affected Leg** on a line – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
5) Standing with feet apart on a line – Eyes Closed	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
6) Walking forward Heel-to-Toe on a line	steps	steps	Raw	0	1-2	3-4	5	6	
			Point	**0**	**1**	**2**	**3**	**4**	
7) Standing on **Unaffected Leg** on a line – Eyes Closed	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
8) Standing on **Affected Leg** on a line – Eyes Closed	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
9) Standing on **Unaffected Leg** on a balance beam – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
10) Standing on **Affected Leg** on a balance beam – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
11) Standing Heel-to-Toe on a balance beam	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
12) Standing on **Unaffected Leg** on a balance beam – Eyes Closed	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
13) Standing on **Affected Leg** on a balance beam – Eyes Open	secs	secs	Raw	0.0-0.9	1.0-2.9	3.0-5.9	6.0-9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
Total Point Score:									**/ 52**

Notes and Comments:

University of Cape Town

Adapted Version of Subtest 6: Running Speed and Agility of the BOT-2

Activity	Trial 1	Trial 2														Point Score
1) Shuttle Run	secs	secs	Raw	>/= 16.0	14.0-15.9	13.0-13.9	12.0-12.9	11.0-11.9	10.0-10.9	9.0-9.9	8.0-8.9	7.5-7.9	7.0-7.4	6.5-6.9	6.0-6.4	</= 5.9	
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
2) Stepping Sideways over a balance beam	steps	steps	Raw	0	1-2	3-5	6-9	10-14	15-19	20-24	25-29	30-39	40-49	>/= 50			
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
3) One-Legged Stationary Hop- **Unaffected Leg**	hops	hops	Raw	0	1-2	3-5	6-9	10-14	15-19	20-24	25-29	30-39	40-49	>/= 50			
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
4) One-Legged Stationary Hop - **Affected Leg**	hops	hops	Raw	0	1-2	3-5	6-9	10-14	15-19	20-24	25-29	30-39	40-49	>/= 50			
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
5) One-Legged Side Hop – **Unaffected Leg**	hops	hops	Raw	0	1-2	3-5	6-9	10-14	15-19	20-24	25-29	30-39	40-49	>/= 50			
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
6) One-Legged Side Hop- **Affected Leg**	hops	hops	Raw	0	1-2	3-5	6-9	10-14	15-19	20-24	25-29	30-39	40-49	>/= 50			
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
7) Two-Legged Side Hop	hops	hops	Raw	0	1-2	3-5	6-9	10-14	15-19	20-24	25-29	30-39	40-49	>/= 50			
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
Total Point Score:																	**/72**

Notes and Comments:

University of Cape Town

8.5 Individual log sheets of gaming order

University of Cape Town

University of Cape Town

Individual Log Sheet of Gaming

Name of Child:
Date of Birth:
Physiotherapist monitoring gaming:

Log of gaming order:
To guarantee that balance is trained in all directions fairly equally, please ensure that:

- Each section of weight shifting is played at least 6 times.
- Each game should be played for at least 10 minutes and each session the child may choose 2 different games.
- At the end of the 3 weeks, each section should have at least 6 ticks and each game should have been played at least once.
- Try to rotate through games as much as possible. Do not allow the child to play the same game 2 sessions in a row.

University of Cape Town

Weight shift section	Number of times played (indicate with a tick)
Antero-posterior weight shifting	Snowboarding:
Lateral weight shifting	Skiing: Penguin game: Soccer:
Multidirectional weight shifting	Bubble game: Hoola-hoops (under cardio games):

Week 1

Session 1								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
Session 2								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
Session 3								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
Session 4								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
If the child was absent for any of these session, please state how often and why:								

University of Cape Town

Week 2

Session 1								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
Session 2								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
Session 3								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
Session 4								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
If the child was absent for any of these session, please state how often and why:								

University of Cape Town

Week 3

Session 1								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
Session 2								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
Session 3								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
Session 4								
Total time spent on Wii Fit								
Resting time								
Game 1:								
Score								
Game 2:								
Score								
If the child was absent for any of these session, please state how often and why:								

University of Cape Town

8.6 Chi-Square analysis tables

To investigate which demographic and medical variables were predictive of a medium to large improvement on the Balance, Running Speed and Agility or TUDS outcome measures, Chi-Square analyses were done of each of the variables against the outcome measure scores. The only significant associations that were found were between Balance and "Previous Surgery" (p = 003) and Balance and "Academic Achievement" (p = 0.009). All other scores did not demonstrate significant associations. Therefore only Balance Score Chi-Square results are presented below. Complete tables of Demographic variables and MAS scores can be found in the Results section.

Cross-tabulation of Balance and Side of Hemiplegia

		Side of Hemiplegia		
		Left	Right	Total
Balance	No Change	2	1	3
	Improvement	5	6	11
Total		7	7	14

Chi-Square analysis of Balance and Hemiplegia

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.424[a]	1	.515		

University of Cape Town

Crosstabulation of Balance and Acquired/Congenital Hemiplegia

		Acquired or Congenital		
		Acquired	Congenital	Total
Balance	No Change	1	2	3
	Improvement	4	7	11
Total		5	9	14

Chi-Square analysis of Balance and Acquired/Congenital Hemiplegia

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.009[a]	1	.923		

University of Cape Town

Cross-tabulation of Balance and AFO

		AFO			
		No	Not anymore	Yes	Total
Balance	No Change	2	1	0	3
	Improvement	6	2	3	11
Total		8	3	3	14

Chi-Square analysis of Balance and AFO

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.131[a]	2	.568

Cross-tabulation of Balance and Previous Surgery

		Previous Surgery		
		No	Yes	Total
Balance	No Change	0	3	3
	Improvement	2	9	11
Total		2	12	14

Chi-Square analysis of Balance and Previous Surgery

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.636[a]	1	.425		

University of Cape Town

Cross-tabulation of Balance and Medication

		Medication		
		No	Yes	Total
Balance	No Change	3	0	3
	Improvement	9	2	11
Total		12	2	14

Chi Square analysis of Balance and Medication

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.636[a]	1	.425		

Cross-tabulaton of Balance and Academic Achievement

		Academic Achievement		
		Satisfactory	Unsatisfactory	Total
Balance	No Change	2	1	3
	Improvement	7	4	11
Total		9	5	14

Chi-Square analysis of Balance and Academic Achievement

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.009[a]	1	.923		

University of Cape Town

Cross-tabulation of Balance and GMFCS level

		GMFCS level		
		Level I	Level II	Total
Balance	No Change	1	2	3
	Improvement	4	7	11
Total		5	9	14

Chi-Square analysis of Balance and GMFCS level

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.009[a]	1	.923		

Cross-tabulation of Balance and Therapy at Baseline

		Conventional therapy		
		Therapy	No Therapy	Total
Balance	No Change	1	2	3
	Improvement	9	2	11
Total		10	4	14

Chi-Square analysis of Balance and Therapy at Baseline

	Value	df
Pearson Chi-Square	.099	1

University of Cape Town

Cross-tabulation of Balance and Triceps Surae MAS score

		Triceps Surae MAS score			
		0	1	2	Total
Balance	No Change	0	2	1	3
	Improvement	1	7	3	11
Total		1	9	4	14

Chi-Square analysis of Balance and Triceps Surae MAS score

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.306[a]	2	.858

Cross-tabulation of Balance and Hamstring MAS score

		Hamstring MAS score		
		0	1	Total
Balance	No Change	1	2	3
	Improvement	2	9	11
Total		3	11	14

Chi-Square analysis of Balance and Hamstring MAS score

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.321[a]	1	.571

Cross-tabulation of Balance and Quadriceps MAS score

		Quadriceps MAS score		
		0	1	Total
Balance	No Change	3	0	3
	Improvement	6	5	11
Total		9	5	14

Chi-Square analysis of Balance and Quadriceps MAS score

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.121[a]	1	.145

University of Cape Town

Cross-tabulation of Running Speed and Agility and Side of Hemiplegia

		Side of Hemiplegia		
		Left	Right	Total
RSandA	No Change	2	3	5
	Improvement	5	4	9
Total		7	7	14

Chi-Square analysis of Running Speed and Agility and Side of Hemiplegia

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.311[a]	1	.577		

University of Cape Town

Cross-tabulation of Running Speed and Agility and Acquired/Congenital Hemiplegia

		Acquired or Congenital		
		Acquired	Congenital	Total
RSandA	No Change	2	3	5
	Improvement	3	6	9
Total		5	9	14

Chi-Square analysis of Running Speed and Agility and Acquired/Congenital Hemiplegia

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.062[a]	1	.803		

Cross-tabulation of Running Speed and Agility and AFO

		AFO			
		No	Not anymore	Yes	Total
RSandA	.00	2	2	1	5
	1.00	6	1	2	9
Total		8	3	3	14

Chi-Square analysis of Running Speed and Agility and AFO

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.659[a]	2	.436

University of Cape Town

Cross-tabulation of Running Speed and Agility and Previous Surgery

		Previous Surgery		
		No	Yes	Total
RSandA	No Change	0	5	5
	Improvement	2	7	9
Total		2	12	14

Chi-Square analysis of Running Speed and Agility and Previous Surgery

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.296[a]	1	.255		

Cross-tabulation of Running Speed and Agility and Medication

		Medication		
		None	Yes	Total
RSandA	No Change	4	1	5
	Improvement	8	1	9
Total		12	2	14

Chi-Square of Running Speed and Agility and Medication

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.207[a]	1	.649		

University of Cape Town

Cross-tabulation of Running Speed and Agility and Academic Achievement

		Academic Achievement		
		Satisfactory	Unsatisfactory	Total
RSandA	No Change	5	0	5
	Improvement	4	5	9
Total		9	5	14

Chi-Square analysis of Running Speed and Agility and Academic Achievement

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.321[a]	1	.038		

Cross-tabulation of Running Speed and Agility and GMFCS level

		GMFCS		
		1.00	2.00	Total
RSandA	No Change	1	4	5
	Improvement	4	5	9
Total		5	9	14

Chi-Square analysis of Running Speed and Agility and GMFCS level

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.837[a]	1	.360		

Cross-tabulation of Running Speed and Agility and Therapy at Baseline

		Conventional therapy		
		Therapy	No Therapy	Total
Running Speed and Agility	No Change	4	1	5
	Improvement	6	3	9
Total		10	4	14

Chi-Square analysis of Running Speed and Agility and Therapy at Baseline

	Value	df
Pearson Chi-Square	.597	1

University of Cape Town

Cross-tabulation of Running Speed and Agility and Triceps Surae MAS score

		Triceps Surae MAS score			
		0	1	2	Total
RSandA	No Change	0	4	1	5
	Improvement	1	5	3	9
Total		1	9	4	14

Chi-Square analysis of Running Speed and Agility and Triceps Surae MAS score

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.054[a]	2	.590

University of Cape Town

Cross-tabulation of Running Speed and Agility and Hamstring MAS score

		Hamstring MAS score		
		0	1	Total
RSandA	No Change	0	5	5
	Improvement	3	6	9
Total		3	11	14

Chi-Square analysis of Running Speed and Agility and Hamstring MAS score

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.121[a]	1	.145		

Cross-tabulation of Running Speed and Agility and Quadriceps MAS score

		Quadriceps MAS score		
		0	1	Total
RSandA	No Change	3	2	5
	Improvement	6	3	9
Total		9	5	14

Chi-Square analysis of Running Speed and Agility and Quadriceps MAS score

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.062[a]	1	.803		

University of Cape Town

TUDS and Side of Hemiplegia

		Side of Hemiplegia		
		Left	Right	Total
TUDS	No Change	3	5	8
	Improvement	4	2	6
Total		7	7	14

Chi-Square analysis of TUDS and Side of Hemiplegia

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.167[a]	1	.280		

Cross-tabulation of TUDS and Acquired/Congenital Hemiplegia

		Acquired or Congenital		
		Acquired	Congenital	Total
TUDS	No Change	3	5	8
	Improvement	2	4	6
Total		5	9	14

Chi-Square analysis of TUDS and Acquired/Congenital Hemiplegia

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.026[a]	1	.872		

University of Cape Town

Cross-tabulation of TUDS and AFO

		AFO			
		No	No anymore	Yes	Total
TUDS	No Change	5	3	0	8
	Improvement	3	0	3	6
Total		8	3	3	14

Chi-Square analysis of TUDS and AFO

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.344[a]	2	.042

Cross-tabulation of TUDS and Previous Surgery

		Previours Surgery		
		No	Yes	Total
TUDS	No Change	1	7	8
	Improvement	1	5	6
Total		2	12	14

Chi-Square analysis of TUDS and Previous Surgery

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.049[a]	1	.825		

University of Cape Town

Cross-tabulation of TUDS and Medication

		Medication		
		None	Yes	Total
TUDS	No Change	8	0	8
	Improvement	4	2	6
Total		12	2	14

Chi-Square analysis of TUDS and Medication

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.111[a]	1	.078		

Cross-tabulation of TUDS and Academic Achievement

		Academic Achievement		
		Satisfactory	Unsatisfactory	Total
TUDS	No Change	6	2	8
	Improvement	3	3	6
Total		9	5	14

Chi-Square analysis of TUDS and Academic Achievement

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.933[a]	1	.334		

Cross-tabulation of TUDS and GMFCS level

		GMFCS level		
		Level I	Level II	Total
TUDS	No Change	3	5	8
	Improvement	2	4	6
Total		5	9	14

Chi-Square of TUDS and GMFCS level

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.026[a]	1	.872		

University of Cape Town

Cross-tabulation of TUDS and Therapy at Baseline

		Conventional therapy		
		Therapy	No Therapy	Total
TUDS	No Change	4	4	8
	Improvement	6	0	6
Total		10	4	14

Chi-Square analysis of TUDS and Therapy at Baseline

	Value	df
Pearson Chi-Square	.040	1

University of Cape Town

Cross-tabulation of TUDS and Triceps Surae MAS score

		Triceps Surae MAS score			
		0	1	2	Total
TUDS	No Change	0	6	2	8
	Improvement	1	3	2	6
Total		1	9	4	14

Chi-Square analysis of TUDs and Triceps Surae MAS score

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.750[a]	2	.417

Cross-tabulation of TUDS and Hamstring MAS score

		Hamstring MAS score		
		0	1	Total
TUDS	No Change	2	6	8
	Improvement	1	5	6
Total		3	11	14

Chi-Square analysis of TUDS and Hamstring MAS score

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.141[a]	1	.707		

University of Cape Town

Cross-tabulation of TUDS and Quadriceps MAS score

		Quadriceps MAS score		
		0	1	Total
TUDS	No Change	6	2	8
	Improvement	3	3	6
Total		9	5	14

Chi-Square analysis of TUDS and Quadriceps MAS score

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.933[a]	1	.334		

University of Cape Town

8.7 GMFM score sheet
296

University of Cape Town

University of Cape Town

GROSS MOTOR FUNCTION MEASURE (GMFM)
SCORE SHEET (GMFM-88 and GMFM-66 scoring)

Version 1.0

Child's Name: _____ ID #: _____

Assessment date: _____ (year / month / day)

Date of birth: _____ (year / month / day)

Chronological age: _____ (years/months)

GMFCS Level [1]

☐ I ☐ II ☐ III ☐ IV ☐ V

Testing Conditions (eg, room, clothing, time, others present)

Evaluator's Name: _____

_____

_____

_____

The GMFM is a standardized observational instrument designed and validated to measure change in gross motor function over time in children with cerebral palsy. The scoring key is meant to be a general guideline. However, most of the items have specific descriptors for each score. It is imperative that the guidelines contained in the manual be used for scoring each item.

SCORING KEY
0 = does not initiate
1 = initiates
2 = partially completes
3 = completes
NT = Not tested [used for the GMAE scoring*]

It is now important to differentiate a true score of "0" (child does not initiate) from an item which is Not Tested (NT) if you are interested in using the GMFM-66 Ability Estimator Software.

*The GMFM-66 Gross Motor Ability Estimator (GMAE) software is available with the GMFM manual (2002). The advantage of the software is the conversion of the ordinal scale into an interval scale. This will allow for a more accurate estimate of the child's ability and provide a measure that is equally responsive to change across the spectrum of ability levels. Items that are used in the calculation of the GMFM-66 score are shaded and identified with an asterisk (*). The GMFM-66 is only valid for use with children who have cerebral palsy.

University of Cape Town

Contact for Research Group:
Dianne Russell, *CanChild* Centre for Childhood Disability Research, McMaster University, Institute for Applied Health Sciences, McMaster University, 1400 Main St. W., Rm. 408, Hamilton, L8S 1C7
Tel: North America - 1 905 525-9140 Ext: 27850
Tel: All other countries - 001 905 525-9140 Ext: 27850
E-mail: canchild@mcmaster.ca Fax: 1 905 522-6095
Website: www.fhs.mcmaster.ca/canchild

[1] GMFCS level is a rating of severity of motor function. Definitions are found in Appendix I of the GMFM manual (2002).

© Mac Keith Press, 2002

Check (✓) the appropriate score: if an item is not tested (NT), circle the item number in the right column

Item	A: LYING & ROLLING	SCORE				NT
1.	SUP, HEAD IN MIDLINE: TURNS HEAD WITH EXTREMITIES SYMMETRICAL	0☐	1☐	2☐	3☐	1.
* 2.	SUP: BRINGS HANDS TO MIDLINE, FINGERS ONE WITH THE OTHER	0☐	1☐	2☐	3☐	2.
3.	SUP: LIFTS HEAD 45°	0☐	1☐	2☐	3☐	3.
4.	SUP: FLEXES R HIP AND KNEE THROUGH FULL RANGE	0☐	1☐	2☐	3☐	4.
5.	SUP: FLEXES L HIP AND KNEE THROUGH FULL RANGE	0☐	1☐	2☐	3☐	5.
* 6.	SUP: REACHES OUT WITH R ARM, HAND CROSSES MIDLINE TOWARD TOY	0☐	1☐	2☐	3☐	6.
* 7.	SUP: REACHES OUT WITH L ARM, HAND CROSSES MIDLINE TOWARD TOY	0☐	1☐	2☐	3☐	7.
8.	SUP: ROLLS TO PR OVER R SIDE	0☐	1☐	2☐	3☐	8.
9.	SUP: ROLLS TO PR OVER L SIDE	0☐	1☐	2☐	3☐	9.
* 10.	PR: LIFTS HEAD UPRIGHT	0☐	1☐	2☐	3☐	10.
11.	PR ON FOREARMS: LIFTS HEAD UPRIGHT, ELBOWS EXT., CHEST RAISED	0☐	1☐	2☐	3☐	11.
12.	PR ON FOREARMS: WEIGHT ON R FOREARM, FULLY EXTENDS OPPOSITE ARM FORWARD	0☐	1☐	2☐	3☐	12.
13.	PR ON FOREARMS: WEIGHT ON L FOREARM, FULLY EXTENDS OPPOSITE ARM FORWARD	0☐	1☐	2☐	3☐	13.
14.	PR: ROLLS TO SUP OVER R SIDE	0☐	1☐	2☐	3☐	14.
15.	PR: ROLLS TO SUP OVER L SIDE	0☐	1☐	2☐	3☐	15.
16.	PR: PIVOTS TO R 90° USING EXTREMITIES	0☐	1☐	2☐	3☐	16.
17.	PR: PIVOTS TO L 90° USING EXTREMITIES	0☐	1☐	2☐	3☐	17.
	TOTAL DIMENSION A					

Item	B: SITTING	SCORE				NT
* 18.	SUP, HANDS GRASPED BY EXAMINER: PULLS SELF TO SITTING WITH HEAD CONTROL	0☐	1☐	2☐	3☐	18.
19.	SUP: ROLLS TO R SIDE, ATTAINS SITTING	0☐	1☐	2☐	3☐	19.
20.	SUP: ROLLS TO L SIDE, ATTAINS SITTING	0☐	1☐	2☐	3☐	20.
* 21.	SIT ON MAT, SUPPORTED AT THORAX BY THERAPIST: LIFTS HEAD UPRIGHT, MAINTAINS 3 SECONDS	0☐	1☐	2☐	3☐	21.
* 22.	SIT ON MAT, SUPPORTED AT THORAX BY THERAPIST: LIFTS HEAD MIDLINE, MAINTAINS 10 SECONDS	0☐	1☐	2☐	3☐	22.
* 23.	SIT ON MAT, ARM(S) PROPPING: MAINTAINS, 5 SECONDS	0☐	1☐	2☐	3☐	23.
* 24.	SIT ON MAT: MAINTAINS, ARMS FREE, 3 SECONDS	0☐	1☐	2☐	3☐	24.
* 25.	SIT ON MAT WITH SMALL TOY IN FRONT: LEANS FORWARD, TOUCHES TOY, RE-ERECTS WITHOUT ARM PROPPING	0☐	1☐	2☐	3☐	25.
* 26.	SIT ON MAT: TOUCHES TOY PLACED 45° BEHIND CHILD'S R SIDE, RETURNS TO START	0☐	1☐	2☐	3☐	26.
* 27.	SIT ON MAT: TOUCHES TOY PLACED 45° BEHIND CHILD'S L SIDE, RETURNS TO START	0☐	1☐	2☐	3☐	27.
28.	R SIDE SIT: MAINTAINS, ARMS FREE, 5 SECONDS	0☐	1☐	2☐	3☐	28.
29.	L SIDE SIT: MAINTAINS, ARMS FREE, 5 SECONDS	0☐	1☐	2☐	3☐	29.
* 30.	SIT ON MAT: LOWERS TO PR WITH CONTROL	0☐	1☐	2☐	3☐	30.
* 31.	SIT ON MAT WITH FEET IN FRONT: ATTAINS 4 POINT OVER R SIDE	0☐	1☐	2☐	3☐	31.
* 32.	SIT ON MAT WITH FEET IN FRONT: ATTAINS 4 POINT OVER L SIDE	0☐	1☐	2☐	3☐	32.
33.	SIT ON MAT: PIVOTS 90°, WITHOUT ARMS ASSISTING	0☐	1☐	2☐	3☐	33.
* 34.	SIT ON BENCH: MAINTAINS, ARMS AND FEET FREE, 10 SECONDS	0☐	1☐	2☐	3☐	34.
* 35.	STD: ATTAINS SIT ON SMALL BENCH	0☐	1☐	2☐	3☐	35.
* 36.	ON THE FLOOR: ATTAINS SIT ON SMALL BENCH	0☐	1☐	2☐	3☐	36.
* 37.	ON THE FLOOR: ATTAINS SIT ON LARGE BENCH	0☐	1☐	2☐	3☐	37.
	TOTAL DIMENSION B					

©Mac Keith Press, 2002

University of Cape Town

Item	C: CRAWLING & KNEELING	SCORE				NT
38.	PR: CREEPS FORWARD 1.8m (6')	0 ☐	1 ☐	2 ☐	3 ☐	38.
* 39.	4 POINT: MAINTAINS, WEIGHT ON HANDS AND KNEES, 10 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	39.
* 40.	4 POINT: ATTAINS SIT ARMS FREE	0 ☐	1 ☐	2 ☐	3 ☐	40.
* 41.	PR: ATTAINS 4 POINT, WEIGHT ON HANDS AND KNEES	0 ☐	1 ☐	2 ☐	3 ☐	41.
* 42.	4 POINT: REACHES FORWARD WITH R ARM, HAND ABOVE SHOULDER LEVEL	0 ☐	1 ☐	2 ☐	3 ☐	42.
* 43.	4 POINT: REACHES FORWARD WITH L ARM, HAND ABOVE SHOULDER LEVEL	0 ☐	1 ☐	2 ☐	3 ☐	43.
* 44.	4 POINT: CRAWLS OR HITCHES FORWARD 1.8m (6')	0 ☐	1 ☐	2 ☐	3 ☐	44.
* 45.	4 POINT: CRAWLS RECIPROCALLY FORWARD 1.8m (6')	0 ☐	1 ☐	2 ☐	3 ☐	45.
* 46.	4 POINT: CRAWLS UP 4 STEPS ON HANDS AND KNEES/FEET	0 ☐	1 ☐	2 ☐	3 ☐	46.
47.	4 POINT: CRAWLS BACKWARDS DOWN 4 STEPS ON HANDS AND KNEES/FEET	0 ☐	1 ☐	2 ☐	3 ☐	47.
* 48.	SIT ON MAT: ATTAINS HIGH KN USING ARMS, MAINTAINS, ARMS FREE, 10 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	48.
49.	HIGH KN: ATTAINS HALF KN ON R KNEE USING ARMS, MAINTAINS, ARMS FREE, 10 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	49.
50.	HIGH KN: ATTAINS HALF KN ON L KNEE USING ARMS, MAINTAINS, ARMS FREE, 10 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	50.
* 51.	HIGH KN: KN WALKS FORWARD 10 STEPS, ARMS FREE	0 ☐	1 ☐	2 ☐	3 ☐	51.

TOTAL DIMENSION C ☐

Item	D: STANDING	SCORE				NT
* 52.	ON THE FLOOR: PULLS TO STD AT LARGE BENCH	0 ☐	1 ☐	2 ☐	3 ☐	52.
* 53.	STD: MAINTAINS, ARMS FREE, 3 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	53.
* 54.	STD: HOLDING ON TO LARGE BENCH WITH ONE HAND, LIFTS R FOOT, 3 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	54.
* 55.	STD: HOLDING ON TO LARGE BENCH WITH ONE HAND, LIFTS L FOOT, 3 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	55.
* 56.	STD: MAINTAINS, ARMS FREE, 20 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	56.
* 57.	STD: LIFTS L FOOT, ARMS FREE, 10 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	57.
* 58.	STD: LIFTS R FOOT, ARMS FREE, 10 SECONDS	0 ☐	1 ☐	2 ☐	3 ☐	58.
* 59.	SIT ON SMALL BENCH: ATTAINS STD WITHOUT USING ARMS	0 ☐	1 ☐	2 ☐	3 ☐	59.
* 60.	HIGH KN: ATTAINS STD THROUGH HALF KN ON R KNEE, WITHOUT USING ARMS	0 ☐	1 ☐	2 ☐	3 ☐	60.
* 61.	HIGH KN: ATTAINS STD THROUGH HALF KN ON L KNEE, WITHOUT USING ARMS	0 ☐	1 ☐	2 ☐	3 ☐	61.
* 62.	STD: LOWERS TO SIT ON FLOOR WITH CONTROL, ARMS FREE	0 ☐	1 ☐	2 ☐	3 ☐	62.
* 63.	STD: ATTAINS SQUAT, ARMS FREE	0 ☐	1 ☐	2 ☐	3 ☐	63.
* 64.	STD: PICKS UP OBJECT FROM FLOOR, ARMS FREE, RETURNS TO STAND	0 ☐	1 ☐	2 ☐	3 ☐	64.

TOTAL DIMENSION D ☐

University of Cape Town

©Mac Keith Press, 2002

Item		E: WALKING, RUNNING & JUMPING	SCORE				NT
*	65.	STD, 2 HANDS ON LARGE BENCH: CRUISES 5 STEPS TO R	0 ☐	1 ☐	2 ☐	3 ☐	65.
*	66.	STD, 2 HANDS ON LARGE BENCH: CRUISES 5 STEPS TO L	0 ☐	1 ☐	2 ☐	3 ☐	66.
*	67.	STD, 2 HANDS HELD: WALKS FORWARD 10 STEPS	0 ☐	1 ☐	2 ☐	3 ☐	67.
*	68.	STD, 1 HAND HELD: WALKS FORWARD 10 STEPS	0 ☐	1 ☐	2 ☐	3 ☐	68.
*	69.	STD: WALKS FORWARD 10 STEPS	0 ☐	1 ☐	2 ☐	3 ☐	69.
*	70.	STD: WALKS FORWARD 10 STEPS, STOPS, TURNS 180°, RETURNS	0 ☐	1 ☐	2 ☐	3 ☐	70.
*	71.	STD: WALKS BACKWARD 10 STEPS	0 ☐	1 ☐	2 ☐	3 ☐	71.
*	72.	STD: WALKS FORWARD 10 STEPS, CARRYING A LARGE OBJECT WITH 2 HANDS	0 ☐	1 ☐	2 ☐	3 ☐	72.
*	73.	STD: WALKS FORWARD 10 CONSECUTIVE STEPS BETWEEN PARALLEL LINES 20cm (8") APART	0 ☐	1 ☐	2 ☐	3 ☐	73.
*	74.	STD: WALKS FORWARD 10 CONSECUTIVE STEPS ON A STRAIGHT LINE 2cm (3/4") WIDE	0 ☐	1 ☐	2 ☐	3 ☐	74.
*	75.	STD: STEPS OVER STICK AT KNEE LEVEL, R FOOT LEADING	0 ☐	1 ☐	2 ☐	3 ☐	75.
*	76.	STD: STEPS OVER STICK AT KNEE LEVEL, L FOOT LEADING	0 ☐	1 ☐	2 ☐	3 ☐	76.
*	77.	STD: RUNS 4.5m (15'), STOPS & RETURNS	0 ☐	1 ☐	2 ☐	3 ☐	77.
*	78.	STD: KICKS BALL WITH R FOOT	0 ☐	1 ☐	2 ☐	3 ☐	78.
*	79.	STD: KICKS BALL WITH L FOOT	0 ☐	1 ☐	2 ☐	3 ☐	79.
*	80.	STD: JUMPS 30cm (12") HIGH, BOTH FEET SIMULTANEOUSLY	0 ☐	1 ☐	2 ☐	3 ☐	80.
*	81.	STD: JUMPS FORWARD 30 cm (12"), BOTH FEET SIMULTANEOUSLY	0 ☐	1 ☐	2 ☐	3 ☐	81.
*	82.	STD ON R FOOT: HOPS ON R FOOT 10 TIMES WITHIN A 60cm (24") CIRCLE	0 ☐	1 ☐	2 ☐	3 ☐	82.
*	83.	STD ON L FOOT: HOPS ON L FOOT 10 TIMES WITHIN A 60cm (24") CIRCLE	0 ☐	1 ☐	2 ☐	3 ☐	83.
*	84.	STD, HOLDING 1 RAIL: WALKS UP 4 STEPS, HOLDING 1 RAIL, ALTERNATING FEET	0 ☐	1 ☐	2 ☐	3 ☐	84.
*	85.	STD, HOLDING 1 RAIL: WALKS DOWN 4 STEPS, HOLDING 1 RAIL, ALTERNATING FEET	0 ☐	1 ☐	2 ☐	3 ☐	85.
*	86.	STD: WALKS UP 4 STEPS, ALTERNATING FEET	0 ☐	1 ☐	2 ☐	3 ☐	86.
*	87.	STD: WALKS DOWN 4 STEPS, ALTERNATING FEET	0 ☐	1 ☐	2 ☐	3 ☐	87.
*	88.	STD ON 15cm (6") STEP: JUMPS OFF, BOTH FEET SIMULTANEOUSLY	0 ☐	1 ☐	2 ☐	3 ☐	88.

TOTAL DIMENSION E ☐

Was this assessment indicative of this child's "regular" performance? YES ☐ NO ☐

COMMENTS:

University of Cape Town

©Mac Keith Press, 2002

GMFM RAW SUMMARY SCORE

DIMENSION	CALCULATION OF DIMENSION % SCORES	GOAL AREA (indicated with ✓ check)
A. Lying & Rolling	$\frac{\text{Total Dimension A}}{51} = \frac{\quad}{51} \times 100 = \quad\%$	A. ☐
B. Sitting	$\frac{\text{Total Dimension B}}{60} = \frac{\quad}{60} \times 100 = \quad\%$	B. ☐
C. Crawling & Kneeling	$\frac{\text{Total Dimension C}}{42} = \frac{\quad}{42} \times 100 = \quad\%$	C. ☐
D. Standing	$\frac{\text{Total Dimension D}}{39} = \frac{\quad}{39} \times 100 = \quad\%$	D. ☐
E. Walking, Running & Jumping	$\frac{\text{Total Dimension E}}{72} = \frac{\quad}{72} \times 100 = \quad\%$	E. ☐

TOTAL SCORE = $\frac{\%A + \%B + \%C + \%D + \%E}{\text{Total \# of Dimensions}}$

$= \frac{\quad + \quad + \quad + \quad + \quad}{5} = \frac{\quad}{5} = \quad\%$

GOAL TOTAL SCORE = $\frac{\text{Sum of \% scores for each dimension identified as a goal area}}{\text{\# of Goal areas}}$

$= \quad = \quad\%$

GMFM-66 Gross Motor Ability Estimator Score [1]

GMFM-66 Score = _____ _____ to _____ 95% Confidence Intervals

previous GMFM-66 Score = _____ _____ to _____ 95% Confidence Intervals

change in GMFM-66 = _____

[1] from the Gross Motor Ability Estimator (GMAE) Software

University of Cape Town

TESTING WITH AIDS/ORTHOSES

Indicate below with a check (✓) which aid/orthosis was used and what dimension it was first applied. (There may be more than one).

AID		DIMENSION	ORTHOSIS		DIMENSION
Rollator/Pusher	☐	___	Hip Control	☐	___
Walker	☐	___	Knee Control	☐	___
H Frame Crutches	☐	___	Ankle-Foot Control	☐	___
Crutches	☐	___	Foot Control	☐	___
Quad Cane	☐	___	Shoes	☐	___
Cane	☐	___	None	☐	___
None	☐	___	Other	☐	___
Other	☐	___	_____ (please specify)		
_____ (please specify)					

RAW SUMMARY SCORE USING AIDS/ORTHOSES

DIMENSION	CALCULATION OF DIMENSION % SCORES	GOAL AREA (indicated with ✓ check)
F. Lying & Rolling	$\frac{\text{Total Dimension A}}{51} = \frac{\quad}{51} \times 100 = \quad\%$	A. ☐
G. Sitting	$\frac{\text{Total Dimension B}}{60} = \frac{\quad}{60} \times 100 = \quad\%$	B. ☐
H. Crawling & Kneeling	$\frac{\text{Total Dimension C}}{42} = \frac{\quad}{42} \times 100 = \quad\%$	C. ☐
I. Standing	$\frac{\text{Total Dimension D}}{39} = \frac{\quad}{39} \times 100 = \quad\%$	D. ☐
J. Walking, Running & Jumping	$\frac{\text{Total Dimension E}}{72} = \frac{\quad}{72} \times 100 = \quad\%$	E. ☐

TOTAL SCORE = $\frac{\%A + \%B + \%C + \%D + \%E}{\text{Total \# of Dimensions}}$

$= \frac{\quad + \quad + \quad + \quad + \quad}{5} = \frac{\quad}{5} = \quad\%$

GOAL TOTAL SCORE = $\frac{\text{Sum of \% scores for each dimension identified as a goal area}}{\text{\# of Goal areas}}$

$= \frac{\quad}{\quad} = \quad\%$

GMFM-66 Gross Motor Ability Estimator Score [1]

GMFM-66 Score = _____ _____ to _____ 95% Confidence Intervals

previous GMFM-66 Score = _____ _____ to _____ 95% Confidence Intervals

change in GMFM-66 = _____

[1] from the Gross Motor Ability Estimator (GMAE) Software

©Mac Keith Press, 2002

University of Cape Town

8.8 Original BOT-2 Subtest 5: Balance and Subtest 6: Running Speed and Agility

188

University of Cape Town

University of Cape Town

Subtest 5: **Balance**

Conduct the second trial only if the examinee does not earn the maximum score on the first trial.	Raw Score Trial 1	Raw Score Trial 2						Point Score
1 Standing with Feet Apart on a Line—Eyes Open	seconds	seconds	Raw	0.0–0.9	1.0–2.9	3.0–5.9	6.0–9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
2 Walking Forward on a Line	steps	steps	Raw	0	1–2	3–4	5	6	
			Point	**0**	**1**	**2**	**3**	**4**	
3 Standing on One Leg on a Line—Eyes Open	seconds	seconds	Raw	0.0–0.9	1.0–2.9	3.0–5.9	6.0–9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
4 Standing with Feet Apart on a Line—Eyes Closed	seconds	seconds	Raw	0.0–0.9	1.0–2.9	3.0–5.9	6.0–9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
5 Walking Forward Heel-to-Toe on a Line	steps	steps	Raw	0	1–2	3–4	5	6	
			Point	**0**	**1**	**2**	**3**	**4**	
6 Standing on One Leg on a Line—Eyes Closed	seconds	seconds	Raw	0.0–0.9	1.0–2.9	3.0–5.9	6.0–9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
7 Standing on One Leg on a Balance Beam—Eyes Open	seconds	seconds	Raw	0.0–0.9	1.0–2.9	3.0–5.9	6.0–9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
8 Standing Heel-to-Toe on a Balance Beam	seconds	seconds	Raw	0.0–0.9	1.0–2.9	3.0–5.9	6.0–9.9	10	
			Point	**0**	**1**	**2**	**3**	**4**	
9 Standing on One Leg on a Balance Beam—Eyes Closed	seconds	seconds	Raw	0.0–0.9	1.0–2.9	3.0–4.9	5.0–7.9	8.0–9.9	10
			Point	**0**	**1**	**2**	**3**	**4**	**5**

Notes & Observations

Total Point Score Subtest 5 (max = 37)

Subtest 6: **Running Speed and Agility**

Conduct the second trial only if the examinee stumbles or falls on the first trial.	Raw Score Trial 1	Raw Score Trial 2												Point Score
1 Shuttle Run	seconds	seconds	Raw	≥16.0	14.0–15.9	13.0–13.9	12.0–12.9	11.0–11.9	10.0–10.9	9.0–9.9	8.0–8.9	7.5–7.9	7.0–7.4	6.5–6.9	6.0–6.4	≤5.9
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2 Stepping Sideways over a Balance Beam	steps	steps	Raw	0	1–2	3–5	6–9	10–14	15–19	20–24	25–29	30–39	40–49	≥50		
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
3 One-Legged Stationary Hop	hops	hops	Raw	0	1–2	3–5	6–9	10–14	15–19	20–24	25–29	30–39	40–49	≥50		
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
4 One-Legged Side Hop	hops	hops	Raw	0	1–2	3–5	6–9	10–14	15–19	20–24	25–29	30–34	35–39	≥40		
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
5 Two-Legged Side Hop	hops	hops	Raw	0	1–2	3–5	6–9	10–14	15–19	20–24	25–29	30–39	40–49	≥50		
			Point	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		

Notes & Observations

Total Point Score Subtest 6 (max = 52)

University of Cape Town

University of Cape Town

8.9 The Modified Ashworth Scale

297

University of Cape Town

University of Cape Town

The Modified Ashworth Scale:

0	No increase in muscle tone
1	Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of range of motion (ROM) when the affected part(s) is moved in flexion or extension
1+	Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM
2	More marked increase in muscle tone through most of ROM, but affected part(s) easily moved
3	Considerable increase in muscle tone, passive movement difficult
4	Affected part(s) rigid in flexion or extension

Quadriceps: With the patient in supine, move the knee from full extension to full flexion.

Hamstrings: With the patient in supine, move the knee from full flexion to full extension.

Gastrocnemius: With the patient in supine, move the ankle from full plantarflexion to full dorsiflexion (measured with the knee extended).

Speed of movement: the movement should take roughly 1 second to complete.

Number of repetitions: each movement may be repeated 2 times before a score is given.

University of Cape Town

University of Cape Town

8.10 The EQ-5D-Y

298

University of Cape Town

University of Cape Town

EQ-5D-Y

Describing your health today

Under each heading, mark the ONE box that best describes your health TODAY

Mobility *(walking about)*

I have no problems walking about ❑
I have some problems walking about ❑
I have a lot of problems walking about ❑

Looking after myself

I have no problems washing or dressing myself ❑
I have some problems washing or dressing myself ❑
I have a lot of problems washing or dressing myself ❑

Doing usual activities *(for example, going to school, hobbies, sports, playing, doing things with family or friends)*

I have no problems doing my usual activities ❑
I have some problems doing my usual activities ❑
I have a lot of problems doing my usual activities ❑

Having pain or discomfort

I have no pain or discomfort ❑
I have some pain or discomfort ❑
I have a lot of pain or discomfort ❑

Feeling worried, sad or unhappy

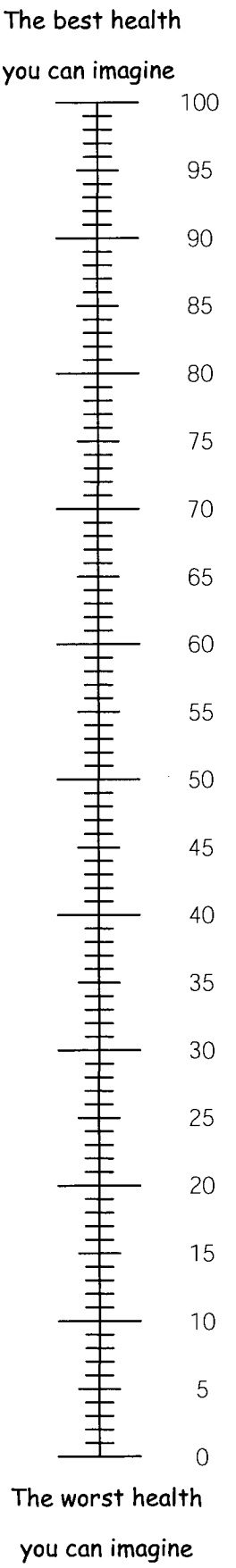
I am not worried, sad or unhappy ❑
I am a bit worried, sad or unhappy ❑
I am very worried, sad or unhappy ❑

University of Cape Town

EQ-5D-Y VAS

How good is your health TODAY

- We would like to know how good or bad your health is TODAY
- This line is numbered from 0 to 100
- 100 means the best health you can imagine
- 0 means the worst health you can imagine
- Please mark an X on the line that shows how good or bad your health is today



University of Cape Town

University of Cape Town