Copyright Statement

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

This thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- Any use you make of these documents or images must be for research or private study purposes only, and you may not make them available to any other person.
- Authors control the copyright of their thesis. You will recognise the author's right to be identified as the author of this thesis, and due acknowledgement will be made to the author where appropriate.
- You will obtain the author's permission before publishing any material from their thesis.

To request permissions please use the Feedback form on our webpage.
http://researchspace.auckland.ac.nz/feedback

General copyright and disclaimer

In addition to the above conditions, authors give their consent for the digital copy of their work to be used subject to the conditions specified on the Library Thesis Consent Form.
Evaluation of clinical outcome measures for children with cerebral palsy.

Anna H. Mackey

BHSc (Physiotherapy), MSc (Neuroscience)

ABSTRACT

There are a lack of reliable and valid clinical outcome measures to assess the effects of medical interventions in children with cerebral palsy, potentially compromising research and clinical practice in this area. The objective of this thesis was to identify and develop reliable outcome measures that could be used to evaluate the effects of botulinum toxin A in children with cerebral palsy.

Six studies were undertaken in both normative and cerebral palsy populations to address this aim. Two studies investigated the reliability and validity of commonly used measures of lower limb function; three-dimensional gait analysis and visual gait assessment. Four studies investigated measures of upper limb function in children with cerebral palsy. An objective three-dimensional measure of upper limb function was developed and used to examine the reliability and validity of additional upper limb measures of muscle tone and arm function and to complete an objective assessment of upper limb botulinum toxin use in this population.

The results demonstrated that three-dimensional and visual gait analyses are reliable and valid measures for children with cerebral palsy. For the upper limb this work has resulted in the development of an objective and reliable three-dimensional kinematic measure of upper limb function. A reliability assessment of the modified Tardieu scale found this measure to have poor reliability in detecting dynamic muscle tone in children with cerebral palsy, indicating limited value as a research tool. The results of the pilot study examining upper limb botulinum toxin A use in a group of ten children with hemiplegia, found small functional gains following treatment, as determined by the three-dimensional kinematic measure and Melbourne Assessment. These two measures were found to have moderate agreement in the determination of range of motion during specific upper limb functional tasks.
This work has established the reliability and validity of a range of measures appropriate for use in children with cerebral palsy. The use of valid and reliable outcome measures provides a greater understanding of the complexities of cerebral palsy and ultimately will lead to improved outcome and greater treatment opportunities for families and children with cerebral palsy.
This research was approved by the Auckland Ethics Committee; Auckland Area Health Board; Maori Research Review Committee and South Auckland Area Health Board. Funding for this research was provided from the Neurological Foundation of New Zealand; University of Auckland, Medical School Foundation, Stevenson’s Trust; University of Auckland Graduate Research Fund and New Zealand Orthopaedic Association, Decade of Bone and Joint. This funding ensured no costs were incurred by the families and participants.

Recognition and gratitude must be given to all the families and participants for volunteering their time and effort to consent to be part of this research.

Thank you very much to my supervisors, Associate Professor Susan Stott and Dr Sharon Walt for the time and effort they gave to me and to this research. The continual positive feedback, expert guidance and support has been very much appreciated throughout this work.

Thank you to the colleagues who assisted and participated in this research; Glenis Lobb, physiotherapist, Gaela Kilgour, physiotherapist, Fiona Miller, occupational therapist and Joanne King, Charge Nurse. Thanks to Christine Ganly for her support and secretarial assistance in preparing this work.

Thank you to students and staff in the Department of Sport and Exercise Science who assisted with data collection; Craig Sutherland, Nicola Reynolds, Anna-Marie Ruhe and to Joanna Stewart from the University of Auckland, Biostatistics Unit for her statistical advice throughout the thesis work.
Thank you to Dr Roslyn Boyd, Melbourne, Australia for her expertise and knowledge, in particular regards to setting up the upper limb botulinum toxin A pilot study. Thank you also to Dr Mary-Clare Waugh, Westmead, New South Wales for freely giving expert advice and guidance on subject selection and muscle selection for the upper limb botulinum toxin A study.

Finally, thank you to my very special family and friends.
TABLE OF CONTENTS

Abstract .......................................................................................................................... ii
Acknowledgements......................................................................................................... iv
Table of Contents........................................................................................................... vi
List of Tables .................................................................................................................. xiii
List of Figures ................................................................................................................ xvi

CHAPTER 1: .................................................................................................................... 1
Introduction ..................................................................................................................... 1
  1.1. The problem ....................................................................................................... 1
  1.2. Aims of the Thesis ............................................................................................ 4
  1.3. Studies Completed to Address Aims: .............................................................. 5
  1.4. Significance of Problem .................................................................................... 7
  1.5. Limitations ....................................................................................................... 7
  1.6. Papers Published from this Thesis .................................................................. 8

CHAPTER 2: .................................................................................................................... 9
Review of the Literature ............................................................................................... 9
  2.1. Introduction ....................................................................................................... 9
  2.2 Cerebral Palsy .................................................................................................... 10
    2.2.1. What is cerebral palsy? ............................................................................. 10
    2.2.2. Aetiology ................................................................................................... 10
    2.2.3. Motor impairments .................................................................................... 13
    2.2.4. Spasticity .................................................................................................. 14
    2.2.5. Classification of cerebral palsy ................................................................. 15
    2.2.6. Clinical presentation of cerebral palsy ..................................................... 17
  2.3. Management of spasticity in children with cerebral palsy ......................... 21
    2.3.1. Aim of medical management .................................................................... 21
    2.3.2. Therapy ..................................................................................................... 22
    2.3.3. Surgery ..................................................................................................... 25
    2.3.4. Botulinum toxin A .................................................................................... 26
      2.3.4.1. Botulinum Toxin A Use in the lower limb ........................................... 29
      2.3.4.2. Botulinum toxin A use in the upper limb .......................................... 38

vi
2.4 Clinical outcome measures ................................................................. 45
  2.4.1. Requirements of an outcome measure ........................................... 45
  2.4.2. International Classification of Functioning, Disability and Health (ICF)  48
2.5. Outcome measures in cerebral palsy .................................................. 49
  2.5.1. Measures of spasticity ................................................................. 56
  2.5.2. Passive range of motion .............................................................. 60
  2.5.3. Visual assessment of gait patterns ................................................ 61
  2.5.4. Three-dimensional gait analysis .................................................... 63
  2.5.5. Gross Motor Function Measure (GMFM) ........................................ 67
  2.5.6. Quest and Melbourne upper limb assessment ................................... 68
  2.5.7. Three-dimensional upper limb movement analysis ............................ 70
  2.5.8. Pediatric Evaluation of Disability Inventory (PEDI) .......................... 73
  2.5.9. Canadian Occupational Performance Measure (COPM) ...................... 74
  2.5.10. Goal Attainment Scale .................................................................. 75
2.6. Limitations to previous research ........................................................ 75

CHAPTER 3: ..................................................................................................... 78
Investigation of the Reliability of Lower Limb Three-Dimensional Kinematics in Children
  with Cerebral Palsy and Unimpaired children ........................................... 78
  3.1. Prologue ............................................................................................... 78
  3.2. Introduction ......................................................................................... 78
  3.3. Methods .............................................................................................. 79
    3.3.1. Subjects ......................................................................................... 79
    3.3.2. Testing procedures ........................................................................ 80
    3.3.3. Data analysis ................................................................................ 81
    3.3.4. Statistical analysis ......................................................................... 81
  3.4. Results .................................................................................................. 82
    3.4.1. Temporal-spatial gait parameters in unimpaired children have high levels of reliability ................................................................. 82
    3.4.2. Temporal-spatial gait parameters in children with cerebral palsy have high levels of repeatability ......................................................... 84
    3.4.3. High levels of reliability in lower limb kinematics for unimpaired children ................................................................. 85
    3.4.4. High levels of reliability for lower limb kinematics in children with cerebral palsy ................................................................. 89
CHAPTER 4: Investigation of the Reliability and Validity of the Observational Gait Scale in Children with Cerebral Palsy - Using Three-Dimensional Gait Analysis as the Criterion Measure

4.1. Prologue

4.2. Introduction

4.2.1. Visual gait scales

4.2.2. The Observational Gait Scale (OGS)

4.3. Methods

4.3.1. Subjects

4.3.2. Observers

4.3.3. Determination of reliability and validity

4.3.4. Statistical analysis

4.4. Results

4.4.1. Different levels of intra-rater reliability for each section of the OGS scale

4.4.2. Inter-rater reliability varies between different sections of the OGS scale

4.4.3. Validity of the first four sections of OGS scale

4.5. Discussion

CHAPTER 5: The Development of a Three-Dimensional Upper Limb Model and Pilot Study of Reliability of Three-Dimensional Upper Limb Kinematics in Children with Cerebral Palsy

5.1. Prologue

5.2. Introduction

5.2.1. Upper limb outcome measures

5.2.2. Upper limb kinematic analysis

5.3. Methods

5.3.1. Subjects

5.3.2. Upper limb 3-D kinematic model

5.3.3. Upper limb tasks

5.3.4. Testing procedures

5.3.5. Data analysis
5.3.6. Statistical analysis................................................. 129
5.4. Results ................................................................. 130
  5.4.1. 3-D upper limb kinematic measures correlate with goniometric measures... 130
  5.4.2. Hand to head and hand to mouth tasks are repeatable.......................... 133
  5.4.3. Upper limb position in gait is reproducible........................................ 133
5.5. Discussion............................................................. 138

CHAPTER 6: ....................................................................... 140
Modification of the Three-Dimensional Upper Limb Model and Standardisation of Upper
Limb Tasks to Improve Reliability: Assessment in Unimpaired children and
Children with Cerebral Palsy ............................................... 140
6.1. Prologue.................................................................. 140
6.2. Introduction .............................................................. 141
6.3. Methods ................................................................ 141
  6.3.1. Subjects............................................................... 141
  6.3.2. Modification of 3-D upper limb model ........................................... 142
  6.3.3. Modification of upper limb tasks .................................................. 147
  6.3.4. Modification to testing procedures .............................................. 150
  6.3.5. Data and statistical analysis ..................................................... 151
6.4. Results .................................................................... 151
  6.4.1. Repeatability of upper limb tasks in unimpaired children................. 151
  6.4.2. Repeatability of upper limb tasks in children with cerebral palsy. .... 154
  6.4.3. Duration to complete upper limb tasks in normative and cerebral palsy
        populations........................................................................ 156
  6.4.4. Range of motion during upper limb tasks for unimpaired children and
        children with cerebral palsy..................................................... 158
6.5. Discussion.................................................................. 165

CHAPTER 7: ....................................................................... 169
Investigation of the Reliability of the Modified Tardieu Scale in the Upper Limb of Children
with Hemiplegia using Three-Dimensional Upper Limb Kinematics as the
Criterion Measure............................................................... 169
7.1. Prologue.................................................................. 169
7.2. Introduction .............................................................. 170
7.2.1. The modified Tardieu scale .......................................................... 170
7.3. Methods ......................................................................................... 172
7.3.1. Subjects ...................................................................................... 172
7.3.2. Three-dimensional upper limb model ........................................ 172
7.3.3. Testing procedures ..................................................................... 172
7.3.4. Data analysis ............................................................................. 173
7.3.5. Statistical analysis ..................................................................... 174
7.4. Results .......................................................................................... 175
7.4.1. R1 and R2 measurements at the elbow have only moderate reliability 175
7.4.2. The R2-R1 calculation has poor reliability in this population in the upper limb ......................................................... 178
7.4.3. The therapist applied angular velocity is variable across subjects. 180
7.5. Discussion ..................................................................................... 183

CHAPTER 8: ............................................................................................. 189
8.1. Prologue ......................................................................................... 189
8.2. Introduction ................................................................................... 189
8.3. Methodology .................................................................................. 191
8.3.1. Subjects ...................................................................................... 191
8.3.2. Upper Limb botulinum toxin A injections ................................... 192
8.3.3. Post injection therapy ................................................................. 195
8.3.4. Outcome Measures .................................................................... 195
8.3.4.1. Three-Dimensional upper limb analysis ................................. 196
8.3.4.2. Melbourne Assessment ............................................................ 196
8.3.4.3. Additional outcome measures ................................................. 197
8.3.5. Adverse effects ......................................................................... 197
8.3.6. Data and statistical analysis ....................................................... 198
8.4. Results ......................................................................................... 201
8.4.1. Significant reduction in muscle tone following BTX A treatment 201
8.4.2. No change in time of 3-D upper limb tasks ................................ 202
8.4.3. No change in 3-D analysis range of movement during upper limb tasks post BTX A ................................................................. 204
8.4.4. Small changes in Melbourne Assessment post BTX A ...................... 214
8.4.5. No change in PEDI scores or grip strengths post BTX A treatment ........ 218
8.4.6. Validity comparison between 3-D analysis and Melbourne Assessment ...... 218
8.5. Discussion.............................................................................. 223

CHAPTER 9: .............................................................................. 228
Summary, Conclusions and Recommendations for Future Research .............. 228
  9.1. Summary............................................................................ 228
  9.2. Lower limb outcome measures................................................... 229
  9.3. Upper limb outcome measures.................................................. 230
  9.4. Conclusions.......................................................................... 234
  9.5. Recommendations for future research......................................... 234

APPENDIX A: ........................................................................... 237
  Auckland Ethics Approval (AKX/02/01/015) ............................................. 237
APPENDIX B: ............................................................................. 238
  Subject Informed Consent Forms (AKX/02/01/015) ............................... 238
APPENDIX C: ............................................................................. 239
  Patient Informed Consent Forms (AKX/02/01/015) .................................. 239
APPENDIX D: ............................................................................. 240
  Information Sheet (AKX/02/01/015) ...................................................... 240
APPENDIX E: ............................................................................. 242
  Auckland Ethics Approval (AKY/03/04/104) ........................................... 242
APPENDIX F: ............................................................................. 244
  Patient Informed Consent (Ethics Approval AKY/03/04/104) ................ 244
APPENDIX G: ............................................................................. 245
  Information sheet (Ethics Approval AKY/03/04/104) ............................... 245
APPENDIX H: ............................................................................. 249
  Information sheet for children (Ethics Approval AKY/03/04/104) ....... 249
APPENDIX I: .............................................................................. 251
  Publisher Article Permission – Gait and Posture .................................. 251
APPENDIX J: .............................................................................. 252
LIST OF TABLES

Table 2.1: Randomised Controlled Trials of Botulinum Toxin A use in the Lower Limbs in Children with Cerebral Palsy .......................................................... 31

Table 2.2: Randomised Controlled Trials of Botulinum Toxin A use in the Upper Limbs in Children with Cerebral Palsy .......................................................... 41

Table 2.3: Reliability and Validity of Lower Limb Outcome Measures evaluating Botulinum Toxin A in Children with Cerebral Palsy .................................................. 50

Table 2.4: Reliability and Validity of Upper Limb Outcome Measures evaluating Botulinum Toxin A in Children with Cerebral Palsy .................................................. 54

Table 3.1: Mean Absolute Difference in Temporal-Spatial Gait Parameters within and between sessions for Unimpaired children. (n= 10). ...................................................... 83

Table 3.2: Mean Absolute Difference in Temporal-Spatial Gait Parameters within and between sessions for Children with Cerebral Palsy .............................................. 84

Table 3.3: Mean Adjusted Coefficient of Multiple Correlation (CMC) for Lower Limb Kinematic Measures during Gait Analysis for Unimpaired children. ......................... 86

Table 3.4: Mean Absolute Differences in Lower Limb Kinematics between Sessions for Unimpaired children. .......................................................... 88

Table 3.5: Mean Adjusted Coefficient of Multiple Correlation (CMC) for Lower Limb Kinematic Measures during Gait Analysis for Children with Cerebral Palsy ...... 90

Table 3.6: Mean Absolute Differences (degrees) in Lower Limb Kinematics between sessions for Children with Cerebral Palsy ...................................................... 92

Table 4.1: Versions of Physicians Rating Scale .......................................................... 99

Table 4.2: Agreement Measures for Kappa Statistics .................................................. 105

Table 4.3: Intra-rater Reliability of each Observer over Two Viewing Sessions ............. 107

Table 4.4: Inter-rater Reliability of Two Observers within One Session ...................... 111
Table 4.5: Comparison between OGS (observer 1 & 2) and OGS derived from 3-DGA .......... 114
Table 5.1: Segment Definitions and Joint Centre Offsets for the Upper Limb Model .......... 128
Table 5.2: Mean Adjusted Coefficient of Multiple Correlation (CMC) for Affected Upper Limb Movements during and to Head and Hand to Mouth Task ..................... 136
Table 5.3: Repeatability of Upper Limb Position during Gait ..................................... 137
Table 6.1: Modified Marker set to obtain 3-D Upper Limb Kinematics ......................... 146
Table 6.2: Repeatability of Upper Limb Kinematics (Non-dominant Limb) in Unimpaired subjects ................................................................. 153
Table 6.3: Repeatability of Upper Limb Kinematics (Affected limb) in Children with Cerebral Palsy ................................................................. 155
Table 6.4: Mean Duration to Complete Upper Limb Tasks for Unimpaired children and Children with Cerebral Palsy ................................................................. 157
Table 6.5: Total Range of Motion during Upper Limb Tasks and Minimum-Maximum Joint Excursion for Unimpaired children and Children with Cerebral Palsy ........... 161
Table 7.1: Intra- and Inter-sessional Absolute Differences in 3-D Kinematic Measures of Joint Angle ................................................................................................................................. 177
Table 7.2: Inter-sessional Absolute Differences in R2-R1 Values ...................................... 179
Table 8.1: Subject Details for Upper Limb Botulinum Toxin A Study ............................... 194
Table 8.2: Summary of Melbourne Assessment Items to be used for Validity Assessment 200
Table 8.3: Mean Time to Complete Each Task (seconds + standard deviation) ............. 203
Table 8.4: Upper Limb Kinematics for Task 1: Hand –Head, showing Mean Total Range of Movement and Minimum and Maximum Range of Movement (degrees) ........ 207
Table 8.5: Upper Limb Kinematics for Task 2: Hand-Mouth 2, showing the Mean Total Range of Movement and Minimum and Maximum Range of Movement (degrees). .................................................. 208

xiv
Table 8.6: Upper Limb Kinematics for Task 3: Reach, showing the Mean Total Range of
Movement and Minimum and Maximum Range of Movement (degrees). .......... 209

Table 8.7: Melbourne Assessment Percentage Total Scores Pre and Post Upper Limb
Botulinum Toxin A Injections. ................................................................. 216
LIST OF FIGURES

Figure 3.1: Representative Frontal, Sagittal and Transverse Plane Kinematic Graphs of Hip
Range of Motion during Gait ................................................................. 87

Figure 3.2: Representative Frontal, Sagittal and Transverse Plane Kinematic Graphs of Hip
Range of Motion during Gait, in a Child with Hemiplegia ................................ 91

Figure 4.1: Stick Figure Representation from 3-DGA (Ortho Trak, Motion Analysis) ........ 104

Figure 4.2: Comparison of OGS scores from Session 1 and Session 2 for Observer 1 and 2. .............................................................................................................. 109

Figure 4.3a: Difference between OGS scores Derived from 3-DGA and from Observer 2
versus the Mean OGS score (Knee Mid Stance & Initial Foot Contact sections). ................................................................. 115

Figure 4.3b: Difference between OGS scores Derived from 3-DGA and from Observer 2
versus the Mean OGS score. (Foot Contact Mid Stance & Timing of Heel Rise
sections). ......................................................................................................... 116

Figure 5.1: Schematic Diagrams (frontal and lateral view) of the Upper Limb Model used for
Three-Dimensional Kinematic Analysis .......................................................... 127

Figure 5.2: Correlation between Goniometer Measure and 3-D Kinematic Model Measure for
Elbow joint (A) and Shoulder joint (C) ............................................................ 132

Figure 5.3: Within Session Kinematic Graphs from one subject, of Elbow Flexion/Extension
(A) and Forearm Supination/Pronation (B), during Hand to Mouth Task using the
Hemiplegic Arm ............................................................................................... 134

Figure 5.4: Between Session Kinematic Graphs from one subject, of Elbow Flexion/Extension
(A) and Forearm Supination/Pronation (B) during Hand to Mouth Task using the
Hemiplegic Arm ............................................................................................... 135
Figure 6.1: Schematic Diagram (frontal and sagittal view) of the Modified Upper Limb Model used for 3-D Kinematic Analysis................................................................. 144

Figure 6.2: Marker Set used for 3-D Upper Limb Data Collection........................................ 145

Figure 6.3: Set Up for 3-D Upper Limb Kinematic Data Collection........................................ 149

Figure 6.4: Between Session Comparison of Shoulder Flexion (A) and Elbow Flexion (B) Kinematics during the Hand–Head Task, from one Subject................................. 164

Figure 7.1: Representative Elbow Position Trace for one subject during Single Trial of the Modified Tardieu Scale................................................................. 177

Figure 7.2: Box and Whisker Plots showing the Range of Angular Velocity applied to the Elbow across Different Subjects for the Three Conditions (slow velocity, gravity velocity and fast velocity)................................................... 182

Figure 7.3: Box and Whisker Plots showing within subject, Intra-and Inter-sessional Differences in Joint Angular Velocity applied to the Elbow for the Three Conditions (slow velocity (V1), gravity velocity (V2) and fast velocity (V3))... 183

Figure 7.4: Correlation between the ‘Angle of Catch’ and the Joint Angular Velocity for Ten Subjects............................................................................................................ 185

Figure 8.1: Mean Time to Complete Five Tasks in 3-D Movement Analysis from Baseline to 24 weeks Post Botulinum Toxin A Treatment......................................................... 203

Figure 8.2: Hand to Head (task 1) Kinematics at Baseline, 6 weeks and 24 weeks Post Botulinum Toxin A Treatment from Representative Child (subject 4)............... 210

Figure 8.3: Sagittal Plane Shoulder (A) and Elbow (B) Kinematics from Representative Child (subject 4) during Task 2: Hand to Mouth......................................................... 211

Figure 8.4: Sagittal Plane Shoulder (A) and Elbow (B) Kinematics for Representative Child (subject 5) during Task 3: (Reach), at Baseline, 6 weeks and 24 weeks Post Botulinum Toxin A................................................................. 212

xvii
Figure 8.5: Sagittal Plane Shoulder (A) and Elbow (B) Kinematics for Task 3: Reach, from Representative Child (subject 3), at all Five Assessment Times .......................... 213

Figure 8.6: Bar Graph of Percentage Change in Melbourne Assessment Score from Baseline to 24 weeks Post Botulinum Toxin A Treatment .............................................. 217

Figure 8.7: Validity Assessment of Range of Movement during Reach Task, Comparing Melbourne Assessment and 3-D Analysis ...................................................... 221

Figure 8.8: Validity Assessment of Range of Movement during Hand to Mouth Task, Comparing Melbourne Assessment and 3-D Analysis ............................................. 222