

**A RANDOMISED CONTROL TRIAL FOR THE RESTORATION OF FUNCTIONAL  
ABILITY IN PATIENTS POST TOTAL KNEE ARTHROPLASTY: A COMPARISON  
OF ECCENTRIC VERSUS CONCENTRIC CYCLING ERGOMETRY**

BY

AMANDA BAKKUM

A thesis submitted for the degree of

**MASTER OF SCIENCE IN MEDICINE (EXERCISE SCIENCE)**

In the Department of Human Biology

Faculty of Health Sciences

University of Cape Town

Division of Exercise Science and Sports Medicine

Sports Science Institute of South Africa

Boundary Road, Newlands, 7700

Cape Town

South Africa

Primary Supervisor: Dr M Posthumus

Co-Supervisors: Dr Y Albertus and Prof M Collins

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.



## DECLARATION

**MSc THESIS TITLE: A RANDOMISED CONTROL TRIAL FOR THE  
RESTORATION OF FUNCTIONAL ABILITY IN PARTICIPANTS POST TOTAL  
KNEE ARTHROPLASTY: A COMPARISON OF ECCENTRIC VERSUS  
CONCENTRIC CYCLING ERGOMETRY**

I, AMANDA BAKKUM, hereby,

- a) Grant the University of Cape Town free license to reproduce the above thesis in whole or in part, for the purpose of research;
- b) Declare that;
- (i) The above thesis is my own unpaid work, both in concept and execution, and that apart from the usual guidance from my supervisor, I have received no assistance;
- (ii) Neither the substance nor any part of the above thesis has been submitted in the past, or is being, or is to be submitted for a degree at this university or at any other university.

I am presenting the thesis for the degree of MSc (Med) Exercise Science.

Signature: 

Signed by candidate
---------------------

 Date: \_\_\_\_\_  
30 October 2015



## ACKNOWLEDGEMENTS

I would like to take this opportunity to express my deepest gratitude to all those individuals involved in the completion of this research thesis. Specifically;

- \* Thank you to my parents, Theo and Brenda for your unwavering support and encouragement throughout this process. Thank you for all your motivation and inspiration over the last few years. This would not be a reality without each of you.
- \* I would like to thank my supervisors Dr. Mike Posthumus, Dr Yumna Albertus and Prof Malcolm Collins for their guidance and support. Thank you for your time and all your help during the undertaking of this thesis.
- \* Thank you to Dr. Willem Van der Merwe and his team at The Sports Science Orthopaedic Clinic for assisting in participant recruitment and maintenance of participants during the implementation of the rehabilitation interventions.
- \* Thank you to my research partner, Sandhya Silal, who worked with me at ground level during the pre and post- intervention testing and throughout the implementation of the rehabilitation interventions.
- \* Thank you to Biomet for funding this project. Your financial contribution was greatly appreciated.
- \* Thank you to the all the institutions that contributed to the completion of this research project and who made this research thesis a possibility. Namely; the National Research Foundation (NRF), the University of Cape Town (UCT) and the Exercise Science and Sports Medicine Unit (ESSM). Your financial and administrative support was vital and greatly appreciated.

## ACKNOWLEDGEMENTS

- \* Thank you to Anton Esterhuysen as well as all the support staff and technical assistants who aided in the administration and analysis of this research. Your contribution was definitely valued.
- \* Thank you to all the staff and students at the Exercise Science and Sports Medicine Research Unit who offered their expert advice and words of wisdom, their time and most importantly their friendship throughout this process.

## TABLE OF CONTENTS

<b>DECLARATION .....</b>	<b>III</b>
<b>ACKNOWLEDGEMENTS .....</b>	<b>V</b>
<b>ABSTRACT .....</b>	<b>XV</b>
<b>LIST OF ABBREVIATIONS .....</b>	<b>XVII</b>
<b>LIST OF TABLES .....</b>	<b>XXIII</b>
<b>LIST OF FIGURES .....</b>	<b>XXIII</b>
<b>CHAPTER 1 .....</b>	<b>1</b>
<b>LITERATURE REVIEW: TOTAL KNEE ARTHROPLASTY AND FACTORS AFFECTING THE OUTCOME .....</b>	<b>1</b>
1.1 INTRODUCTION .....	1
1.2 FACTORS AFFECTING THE OUTCOME OF TKA SURGERY .....	3
1.2.1 Demographic Characteristics .....	3
1.2.2 Obesity .....	5
1.2.3 Preoperative Quadriceps Strength And Functional Level .....	7
1.2.4 Mental Status .....	9
1.2.5 Post-operative Rehabilitation .....	10
1.3 THE EFFECT OF TKA SURGERY ON PHYSICAL AND PSYCHOLOGICAL PARAMETERS .....	11
1.3.1 Muscle Strength Deficits .....	11
1.3.2 Lean Thigh Volume And Muscle Cross- Sectional Area .....	16
1.3.3 The Sit-To-Stand Transfer .....	19
1.3.4 Quality Of Life And Patient Satisfaction .....	22
1.4 REHABILITATION .....	27

1.4.1 What Is The Role Of TKA Rehabilitation .....	27
1.4.2 Types Of TKA Rehabilitation .....	29
1.4.2.1 Standard Rehabilitation .....	29
1.4.2.2 Fast Track Rehabilitation.....	31
1.4.2.3 Rehabilitation Using Neuromuscular Electrical Stimulation.....	33
1.4.2.4 Eccentric Rehabilitation .....	35
1.5 OVERVIEW .....	39
<b>CHAPTER 2 .....</b>	<b>43</b>
<b>AIMS AND OBJECTIVES .....</b>	<b>43</b>
2.1 PURPOSE OF RESEARCH .....	43
2.2 RESEARCH STUDY AIMS .....	45
2.1.1 Study 1 .....	45
2.1.2 Study 2.....	46
2.1.3 Study 3.....	47
2.1.4 Study 4.....	49
<b>CHAPTER 3 .....</b>	<b>51</b>
<b>METHODOLOGY .....</b>	<b>51</b>
3.1 STUDY DESIGN.....	51
3.1.1 Overview Of Trial Procedures.....	51
3.1.2 Recruitment .....	53
3.1.2.1 Inclusion Criteria.....	54
3.1.2.2 Exclusion Criteria.....	55
3.1.3 Sample Size Determination .....	56
3.2.1 Health Questionnaires And Surveys.....	57
3.2.1.1 Knee Injury And Osteoarthritis Outcome Score (KOOS).....	57

3.2.1.2 The SF-36 Health Survey .....	58
3.2.1.3 The Tegner Activity Scale.....	59
3.2.2 Electromyography (EMG) .....	59
3.2.3 Muscle Volume And Cross- Sectional Area .....	61
3.2.4 Isokinetic Strength Assessment.....	61
3.2.5 Motion Capture .....	63
3.2.5.1 Sit-to-Stand Transfer .....	66
3.2.6 Eccentric And Concentric Intervention.....	68
3.2.6.1 Grucox Cycle Ergometer .....	68
3.2.6.2 Rehabilitation Intervention.....	70
3.3 STATISTICAL ANALYSIS .....	74
3.4 SUMMARY OF STUDY PROCESS.....	76
<b>CHAPTER 4 .....</b>	<b>77</b>
<b>STUDY 1: THE FEASIBILITY OF AN ECCENTRIC VERSUS CONCENTRIC CYCLING ERGOMETRY REHABILITATION INTERVENTION IN PATIENTS POST TOTAL KNEE ARTHROPLASTY .....</b>	<b>77</b>
4.1 INTRODUCTION.....	77
4.2 METHODOLOGY .....	79
4.2.1 Participants .....	79
4.2.2 Rehabilitation intervention .....	79
4.2.3 Pain Visual Analogue Scale.....	80
4.2.4 Heart Rate .....	81
4.2.5 Workload.....	81
4.2.6 Statistical Analysis .....	83
4.3 RESULTS.....	84

4.3.1 Descriptive Characteristics .....	84
4.3.2 Intervention Adherence.....	86
4.3.3 Pain Visual Analogue Scale.....	87
4.3.4 Heart Rate .....	89
4.3.5 Workload.....	91
4.3.5.1 Mode Specific Power Output.....	91
4.3.5.2 Work .....	93
4.4 DISCUSSION.....	95
<b>CHAPTER 5 .....</b>	<b>99</b>
<b>STUDY 2: THE EFFECTS OF AN ECCENTRIC VERSUS CONCENTRIC CYCLING ERGOMETRY REHABILITATION INTERVENTION ON MUSCLE STRENGTH, VOLUME AND ACTIVITY IN PATIENTS POST TOTAL KNEE ARTHROPLASTY</b>	<b>99</b>
5.1 INTRODUCTION.....	99
5.2 METHODOLOGY .....	102
5.2.1 Isokinetic Strength Assessment.....	102
5.2.1.1 Peak Torque Per Body Weight.....	102
5.2.1.2 Time To Peak Torque.....	102
5.2.1.3 Torque At 30 Degrees .....	103
5.2.1.4 Total Work .....	103
5.2.1.5 Work Fatigue .....	103
5.2.2 Electromyography.....	104
5.2.2.1 Vastus Medialis Muscle (VM) .....	104
5.2.2.2 Vastus Lateralis Muscle (VL).....	104
5.2.2.3 Biceps Femoris Muscle (BF) .....	105
5.2.3 Electromyography (EMG) to Torque Ratio .....	105

5.2.4 Muscle Volume And Cross- Sectional Area .....	105
5.2.5 Statistical Analysis .....	105
5.3 RESULTS .....	106
5.3.1 Isokinetic Strength Assessment.....	106
5.3.1.1 Peak Torque Per Body Weight .....	106
5.3.1.2 Time To Peak Torque.....	109
5.3.1.3 Torque At 30 Degrees .....	112
5.3.1.4 Total Work .....	115
5.3.1.5 Work Fatigue .....	118
5.3.2 Electromyography .....	121
5.3.2.1 The Vastus Medialis Muscle.....	121
5.3.2.2 The Vastus Lateralis Muscle .....	123
5.3.2.3 The Biceps Femoris Muscle .....	125
5.2.3 Electromyography (EMG) to Torque Ratio .....	127
5.3.4 Muscle Volume And Cross- Sectional Area.....	129
5.4 DISCUSSION .....	131
<b>CHAPTER 6 .....</b>	<b>141</b>
<b>STUDY 3: THE EFFECT OF AN ECCENTRIC VERSUS CONCENTRIC CYCLING ERGOMETRY REHABILITATION INTERVENTION ON SELF REPORT PHYSICAL AND MENTAL HEALTH SURVEYS IN PATIENTS POST TOTAL KNEE ARTHROPLASTY .....</b>	<b>141</b>
6.1 INTRODUCTION .....	141
6.2 METHODOLOGY .....	143
6.2.1 Knee Injury And Osteoarthritis Outcome Score (KOOS) .....	143
6.2.2 SF- 36 Health Survey .....	143

6.2.3 The Tegner Activity Scale .....	144
6.2.4 Statistical Analysis .....	144
6.3 RESULTS .....	145
6.3.1 Knee Injury And Osteoarthritis Outcome Score (KOOS) .....	145
6.3.2 SF- 36 Health Survey .....	147
6.3.3 The Tegner Activity Scale .....	150
6.4 DISCUSSION .....	152
<b>CHAPTER 7 .....</b>	<b>157</b>
<b>STUDY 4: THE SIT-TO-STAND TRANSFER IN PATIENTS POST TOTAL KNEE ARTHROPLASTY AFTER EITHER AN ECCENTRIC OR CONCENTRIC REHABILITATION INTERVENTION: AN EXPLORATORY STUDY .....</b>	<b>157</b>
7.1 INTRODUCTION .....	157
7.2 METHODOLOGY .....	162
7.2.1 The Sit-To-Stand Transfer .....	162
7.2.1.1 Vertical Ground Reaction Force .....	163
7.2.1.2 Anterior-Posterior Ground Reaction Force .....	163
7.2.1.3 Knee Valgus-Varus Angle .....	164
7.2.1.4 Hip Abduction-Adduction Angle .....	164
7.2.2 Electromyography .....	164
7.2.3 Statistical Analysis .....	165
7.3 RESULTS .....	166
7.3.1 Ground Reaction Forces .....	166
7.3.1.1 Vertical Ground Reaction Force .....	166
7.3.1.2 Anterior-Posterior Ground Reaction Force .....	169
7.3.2 Joint Kinematics .....	172

7.3.2.1 Peak Knee Valgus-Varus Angles .....	172
7.3.2.2 Peak Hip Abduction-Adduction Angles.....	177
7.3.3 Sit-To-Stand Electromyography.....	182
7.3.3.1 The Vastus Medialis Muscle.....	182
7.3.3.2 The Vastus Lateralis Muscle .....	185
7.3.3.3 The Biceps Femoris Muscle .....	188
7.4 DISCUSSION .....	191
<b>CHAPTER 8 .....</b>	<b>195</b>
<b>SUMMARY AND CONCLUSIONS.....</b>	<b>195</b>
8.1 OVERVIEW .....	195
8.2 LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH.....	202
8.3 CLINICAL APPLICATIONS .....	205
8.4 CONCLUSION .....	209
<b>REFERENCES .....</b>	<b>211</b>
<b>APPENDIX .....</b>	<b>223</b>
APPENDIX A: INFORMED CONSENT .....	223
APPENDIX B: PATIENT HISTORY .....	226
APPENDIX C: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PARQ) ..	230
APPENDIX D: KNEE INJURY AND OSTEOARTHRITIS OUTCOME SCORE (KOOS) .....	231
APPENDIX E: SF-36 HEALTH SURVEY.....	237
APPENDIX F: TEGNER SCALE.....	240
APPENDIX G: CYCLE ERGOMETRY PROTOCOL.....	241
APPENDIX H: TESTING SHEET .....	242
APPENDIX I: THE BORG RATING OF PERCEIVED EXERTION SCALE .....	245

APPENDIX J: PRESCRIBED INTENSITIES .....	246
APPENDIX K: PAIN VISUAL ANALOGUE SCALE.....	247
APPENDIX L: GRUCOX TESTING SHEET .....	248

**ABSTRACT**

**Purpose:** The predominant impairment to function following a total knee arthroplasty (TKA) is a distinctive reduction in quadriceps muscle strength. It has been suggested that eccentric rehabilitation may be more beneficial than traditional concentric only rehabilitation at improving muscle strength, physical functioning and quality of life in this population. The aim of this study was therefore to determine if an eccentric cycling ergometry rehabilitation intervention (a) was feasible in participant's early after TKA surgery (Study 1), (b) resulted in greater improvements in muscle strength and endurance, as well as muscle activity and muscle volume (Study 2) and, (c) resulted in greater knee functional ability, health related quality of life and physical activity levels (Study 3), when compared to an concentric cycling ergometry rehabilitation intervention. Finally, knee and hip kinematics, ground reaction force and muscle activity was described during the sit-to-stand transfer within this population (Study 4). **Methods:** Eighteen age- and sex-matched participants', three to nine month's post-TKA were recruited and randomly divided into either an eccentric or concentric cycling rehabilitation intervention. The participants were required to perform three exercise sessions a week, over a period of eight weeks. Isokinetic strength and muscle activity of the quadriceps and hamstring muscles, sit-to-stand motion capture analysis and knee functional ability and health related quality of life questionnaires (Knee Injury and Osteoarthritis Outcome Score, SF-36 Health Survey and Tegner Activity Scale) were assessed pre and post- rehabilitation intervention. **Data Analysis:** Two-way repeated-measures analysis of variance were used to analyse the effects of time and the ECC and CON intervention groups and the group/time interaction for each of the dependent variables. Paired t-tests were

used to test for differences between the pre- and post-intervention values for all dependent variables. **Results:** The eccentric rehabilitation intervention was well tolerated with regards to pain levels in participants' as early as three months post-TKA, the peak level of pain perceived per session, never exceeding a "mild" classification. The eccentric intervention resulted in greater power ( $P= 0.029$ ) and work output ( $P\leq 0.001$ ) with a reduced overall heart rate ( $P= 0.014$ ); moderate decreases in biceps femoris (BF) muscle activity (-3.2%) and increases in the lean thigh volume (+807.32) of the uninvolved limb; as well as improvements in the physical functioning (+12.2%) and physical role functioning SF-36 scores (+22.2%) and the level of physical activity (+0.9) (Tegner activity scale). The concentric intervention resulted in decreases in vastus lateralis (VL) muscle activity (-8.17%) and work fatigue (-7.34%) and increases in the lean thigh volume (+677.49) and the hip abduction angle (+2.67°) (sit-to-stand) of the involved limb. **Conclusion:** The eccentric rehabilitation intervention is well tolerated with regards to pain and is characterised by significantly greater power output produced and work performed at significantly lower heart rates. Eccentric cycling ergometry matched in perceived exertion and duration, is associated with greater improvements in physical functioning outcome scores, physical activity level and knee flexion muscle efficiency during concentric contractions, when compared with concentric cycling ergometry. However, knee extensor muscle endurance and efficiency during concentric contractions, as well as muscle volume of the involved limb increased more significantly after concentric training in comparison to eccentric training, Further research is required to establish which training modality is the most feasible and effective in restoring knee function in participant's three months post-TKA.

**LIST OF ABBREVIATIONS**

- \* Abd: Abduction
- \* Abd/Add: Abduction-Adduction
- \* ACL: Anterior Cruciate Ligament
- \* ACSM: American College of Sports Medicine
- \* Add: Adduction
- \* ADL: Activity of Daily Living
- \* AKSS: American Knee Society score
- \* ASIS: Anterior Superior Iliac Spine
- \* BF: Biceps Femoris
- \* BMI: Body Mass Index
- \* CAS: Computer Assisted Surgery
- \* cc: Cubic Centimetres
- \* CON: Concentric
- \* CPM: Continuous Passive Movement
- \* CSA: Cross- Sectional Area
- \* CT: Computerised Tomography
- \* Deg/sec: Degrees per Second
- \* DVT: Deep Vein Thrombosis
- \* ECC: Eccentric
- \* EMG: Electromyography
- \* EMS: Electric Muscle Stimulation
- \* GRF: Ground Reaction Force

- \* HR: Heart Rate
- \* HREC: Human Research Ethics Committee
- \* HRQoL: Health Related Quality of Life
- \* HSS: Hospital for Special Surgery
- \* Hz: Hertz
- \* kg: Kilograms
- \* kJ: Kilojoules
- \* KOOS: Knee Injury and Osteoarthritis Outcome Score
- \* KSS: Knee Society Scores
- \* LANK: Left Ankle
- \* LASI: Left Anterior Superior Iliac
- \* LHEE: Left Heel
- \* LKNE: Left Knee
- \* LOHS: Length of Hospital Stay
- \* LPSI: Left Posterior Superior Iliac
- \* LTHI: Left Thigh
- \* LTIB: Left Tibia
- \* LTV: Lean Thigh Volume
- \* m: Meters
- \* MIS: Minimally Invasive Surgery
- \* MPCl: Minimal Perceptible Clinical Improvement
- \* MR-TKA: Multiple Radius Total Knee Arthroplasty
- \* MRI: Magnetic Resonance Imaging

- \* MVC: Maximum Voluntary Contraction
- \* MVIC: Maximum Voluntary Isometric Contraction
- \* N.m: Newton meters
- \* NMES: Neuromuscular Electrical Stimulation
- \* OA: Osteoarthritis
- \* OKS: Oxford Knee Society Score
- \* PARQ: Physical Activity Readiness Questionnaire
- \* PCI: Physiological Cost Index
- \* PMR: Physical Medicine and Functional Rehabilitation
- \* PTKA: Primary Total Knee Arthroplasty
- \* PTQ/BW: Peak Torque per Body Weight
- \* QA: Quadriceps Muscle Activation
- \* QoL: Quality of Life
- \* QV: Quadriceps Volume
- \* RA: Rheumatoid Arthritis
- \* RANK: Right Ankle
- \* RASI: Right Anterior Superior Iliac
- \* Reps: Repetitions
- \* RHEE: Right Heel
- \* RKNE: Right Knee
- \* 1RM: One Repetition Maximum
- \* ROM: Range of Motion
- \* RPE: Rate of Perceived Exertion
- \* RPM: Repetitions per Minute

- \* RPSI: Right Posterior Superior Iliac
- \* RTHI: Right Thigh
- \* RTIB: Right Tibia
- \* RTKA: Revised Total Knee Arthroplasty
- \* RTOE: Right Toe
- \* s: Seconds
- \* SACR: Sacral
- \* Sport/Rec: Sport and Recreation Subscale
- \* SR- TKA: Single Radius Total Knee Arthroplasty
- \* STS: Sit to Stand
- \* THA: Total Hip Arthroplasty
- \* TJA: Total Joint Arthroplasty
- \* TKA: Total Knee Arthroplasty
- \* TotW: Total Work
- \* TQ30°: Torque at 30 Degrees
- \* TtPTQ: Time to Peak Torque
- \* TUG: Timed Up and Go Test
- \* USA: United States of America
- \* Val: Valgus
- \* Val/Var: Valgus-Varus
- \* Var: Varus
- \* VAS: Visual Analogue Scale
- \* VL: Vastus Lateralis
- \* VM: Vastis Medialis

- \* W: Watts
- \* WF: Work Fatigue
- \* WHO: World Health Organisation
- \* WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index
- \* 6MWT: Six Minute Walk Test
- \* 1RM: One Repetition-Maximum
- \* °: Degrees
- \* “: Inch
- \* %: Percentage
- \* \$: American Dollars



**LIST OF TABLES****Chapter 4:**

Table 4.1. Intervention Group Descriptive Characteristics.....	85
Table 4.2. Pain Visual Analogue Scale (VAS).....	88

**Chapter 5:**

Table 5.1 Force/EMG Ratio.....	128
Table 5.2 A Summary of Muscular Strength and Endurance Results.....	132
Table 5.3 A Summary of Muscular Activity and Area Results.....	133

**Chapter 6:**

Table 6.1 Knee Injury and Osteoarthritis Outcome Score (KOOS) .....	146
Table 6.2 SF-36 Health Survey Results.....	149
Table 6.3 Tegner activity scale Results.....	151

**LIST OF FIGURES****Chapter 3:**

Figure 3.1. STS Marker Placement: Front View.....	64
Figure 3.2. STS Marker Placement: Back View.....	64
Figure 3.3. STS Marker Placement: Side View.....	65
Figure 3.4 Plug-In-Gait Variable Definitions.....	65
Figure 3.5. The Sit-to-Stand Transfer.....	67
Figure 3.6. The Force Plate.....	67
Figure 3.7. Grucox Cycle Ergometer.....	69
Figure 3.8. Grucox Ergometer Touch Display.....	69

Figure 3.9. Summary of Study Process.....	76
---	----

#### **Chapter 4:**

Figure 4.1. Work Formula's.....	82
Figure 4.2 Steps Taken In Each Intervention Session.....	83
Figure 4.3. Borg Perceived Rate of Exertion (RPE).....	86
Figure 4.4. Heart Rate (HR).....	90
Figure 4.5.A. Mode Specific Power Output: Involved Limb.....	92
Figure 4.5.B. Mode Specific Power Output: Uninvolved Limb.....	92
Figure 4.6. Work.....	94
Figure 4.7. Summary of Conclusions.....	98

#### **Chapter 5:**

Figure 5.1.A. Peak Torque per Body Weight: Knee Extension.....	108
Figure 5.1.B. Peak Torque per Body Weight: Knee Flexion.....	108
Figure 5.2.A. Time to Peak Torque: Knee Extension.....	111
Figure 5.2.B. Time to Peak Torque: Knee Flexion.....	111
Figure 5.3.A. Torque at 30 Degrees: Knee Extension.....	114
Figure 5.3.B. Torque at 30 Degrees: Knee Flexion.....	114
Figure 5.4.A. Total Work: Knee Extension.....	117
Figure 5.4.B. Total Work: Knee Flexion.....	117
Figure 5.5.A. Work Fatigue: Knee Extension.....	120
Figure 5.5.B. Work Fatigue: Knee Flexion.....	120
Figure 5.6. Vastus Medialis EMG .....	122
Figure 5.7. Vastus Lateralis EMG.....	124

Figure 5.8. Biceps Femoris EMG .....	126
Figure 5.9. Lean Thigh Volume.....	130
Figure 5.10. Summary of Conclusions.....	139

### **Chapter 6:**

Figure 6.1. Summary of Conclusions.....	156
---	-----

### **Chapter 7:**

Figure 7.1. Peak Vertical Ground Reaction Force .....	168
Figure 7.2. Peak Anterior-Posterior Ground Reaction Force.....	171
Figure 7.3.A Knee Valgus-Varus Angle: Phase One .....	176
Figure 7.3.B Knee Valgus-Varus Angle: Phase Two.....	176
Figure 7.4.A Hip Abduction-Adduction Angle: Phase One.....	181
Figure 7.4.B Hip Abduction-Adduction Angle: Phase Two.....	181
Figure 7.5. Vastus Medialis Muscle Activity .....	184
Figure 7.6. Vastus Lateralis Muscle Activity.....	187
Figure 7.7. Biceps Femoris Muscle Activity.....	190
Figure 7.8. Summary of Conclusions.....	194

### **Chapter 8:**

Figure 8.1. Summary of Conclusions.....	210
---	-----



## CHAPTER 1

# LITERATURE REVIEW: TOTAL KNEE ARTHROPLASTY AND FACTORS AFFECTING THE OUTCOME

## 1.1 INTRODUCTION

The total knee arthroplasty (TKA) is a universally performed surgical procedure in which the weight-bearing surfaces of the knee joint are replaced in an attempt to relieve or alleviate joint pain and disability. More than 500,000 TKAs for severe osteoarthritis (OA) are performed each year in the United States of America, with the expected number to increase by more than 600% to approximately 3.5 million surgical procedures by the year 2030 (Kurtz et al. 2007). This procedure is typically performed on individuals with knee OA or rheumatoid arthritis (RA- a chronic autoimmune disease that causes inflammation and deformity of the joints). Surgery is indicated when radiological findings deteriorate, conservative therapies have failed and the participants symptoms can no longer be medically relieved.

The TKA is a reliable surgical procedure with the goal of enabling patients to regain physical activity (Ethgen et al. 2004), reducing pain and improving quality of life (QoL) (Marx et al. 2005; Callahan et al. 1994; Fitzgerald et al. 2004; Kane et al. 2005; Kiebzak et al. 2002; Schneider et al. 2004; Jones et al. 2000). However, whilst some patients experience successful reductions in their levels of pain and improvements in overall knee function (George et al. 2008; Sloan et al. 2009); more than one-third of the patients experience suboptimal physical function following TKA

surgery (Jones et al. 2000; Franklin et al. 2008; Brander et al. 2003; Dickstein et al. 1998).

The predominant impairment to function following a TKA is a distinctive reduction in quadriceps strength that has been associated with a limitation of post-operative physical activity (Berth et al. 2002; Silva et al. 2003; Walsh et al. 1998; Yoshida et al. 2008). The subsequent muscle strength deficiencies are not well accounted for, however it is suggested that improving quadriceps strength may mitigate these impairments and contribute to improved functional outcomes. Therefore, of particular interest is the role of physical rehabilitation, and how this may serve to offset the distinctive reductions in muscular strength that are present following surgery. There are a number of rehabilitative approaches each with their own advantages and disadvantages. Research suggests that eccentric muscle contractions may elicit superior developments in strength gains and physical functioning and may be an ideal therapeutic modality where functional activity is limited, as in the case of TKA surgery (Lindstedt et al. 2001). In addition to physical rehabilitation, there are a number of aspects to consider that may influence the outcome of TKA surgery. The factors affecting the outcome of TKA surgery, such as demographic characteristics (age and gender), as well as the effect of TKA surgery on physical and psychological parameters will be discussed in detail in the section to follow.

## **1.2 FACTORS AFFECTING THE OUTCOME OF TKA SURGERY**

TKA surgery has a profound effect on a number of factors relating to post-operative physical functioning as well as HRQoL. Not all these effects are beneficial or desirable and some may even hamper activities of daily living (ADL); leaving the patient in a dissatisfied or even depressive state of mind. Thus, determining ways to minimise these negative outcomes and optimise patient recovery and satisfaction is of great concern. In order to do this, the factors influencing TKA outcomes need to be identified and investigated. Interventions can then be developed and aimed at those modifiable factors in order to enhance surgical outcomes. Factors that may influence the outcome of TKA surgery are discussed in the following section.

### **1.2.1 Demographic Characteristics**

It is believed that older age is linked to an increased risk of complications with regards to surgical interventions; thus, healthcare practitioners are hesitant to perform such an invasive surgical procedure such as a TKA in older patients. Elson et al. (2006) showed that younger participants (<60 years) were more likely to experience greater levels of pain and that avoiding TKA surgery in participants younger than 60 years old will reduce the chance of poor pain outcomes. Conversely, Nilsson et al. (2009) prospectively described self-reported outcomes up to five years after TKA surgery and found that older age, to some extent, predicted more post-operative pain (Nilsson et al. 2009). Pulido et al. (2008) showed that older age is a risk factor for more immediate post-operative complications. This study prospectively collected data on systemic and local in

hospital complications after 15 383 joint arthroplasties, of which 7 153 were TKAs. They concluded that total joint arthroplasty (TJA), despite its success, can be associated with rare serious and life-threatening complications, which may be more prevalent as age increases (Pulido et al. 2008).

Santaguida et al. (2008) on the other hand, addressed how participant characteristics influence the outcomes of hip and knee arthroplasty in participants with OA. They concluded that, after TJA, although younger age is associated with increased risk of TKA revision surgery; which could possibly be due to the higher physical demands placed on the prosthesis; older age is associated with increased risk of mortality and is related to poorer function. They also determined that age does not influence the outcome of pain (Santaguida et al. 2008).

The influential role gender plays with regards to determining TKA outcome success is currently under debate. A study by Vincent et al. (2006) examined age and gender effects on outcomes after inpatient rehabilitation in both primary and revision TKA participants. The results showed that female participants typically presented with lower preoperative functional scores, yet they had similar percentage gains overall when compared to their male counterparts. They also showed that female participants did however, take longer to achieve these functional gains resulting in an increased length of hospital stay (LOHS) (Vincent et al. 2006).

Kennedy et al. (2006) explored the predictors of recovery following both TKA and THA surgery. The results showed that gender was a significant predictor for physical performance scores in the first week following surgery, but thereafter, men and

women had similar rates of improvement (Kennedy et al. 2006). A study by Santaguida et al. (2008) addressed how participant characteristics influence the outcomes of hip and knee arthroplasty in participants with OA. They concluded that, although additional research is necessary, their findings suggest that the male sex is associated with increased risk of surgical revision, as well as an increased risk of mortality. Their results also showed that although older age in women specifically may be related to poorer function, sex does not influence the outcome of pain (Santaguida et al. 2008).

In conclusion, older age may be associated with increased risk for post-operative complications as well as increased risk of mortality and poorer function, whilst younger TKA participants may be at a greater risk for surgical revision. However, age alone is not a factor that affects the overall outcome of total joint arthroplasties and should not be a limiting factor when considering who should receive TKA surgery. With regards to gender, female participants typically presented with lower preoperative functional scores, however they showed similar rates of improvement following the first week post surgery and comparable percentage gains overall when compared to their male counterparts. The male gender was associated with increased risk of surgical revision, as well as an increased risk of mortality. Neither age nor gender influenced the outcome of pain following TKA surgery.

### **1.2.2 Obesity**

According to the World Health Organisation (WHO), being overweight and obese is defined as having abnormal or excessive fat accumulation. Body mass index (BMI) is

a simple measure that is commonly used to classify overweight and obesity in adults. Individuals with a BMI greater than or equal to  $25 \text{ kg.m}^{-2}$  are considered overweight and greater than or equal to  $30 \text{ kg.m}^{-2}$  are considered to be obese.

Contemporary studies are conflicting with regards to the relative risk of obesity on complications post-TKA surgery. Overweight and obese participants are often considered poor candidates for TKA surgery; however, the influence of body weight is not yet fully understood. Smith et al. (1992) performed a two-year follow-up study to investigate the effect of participants weight on the functional outcome of TKA surgery. Clinically, the results of this study suggested that orthopaedists can expect their overweight TKA participants to not be at a significant post-operative functional disadvantage because of their weight during the initial, two-year post-operative period (Smith et al. 1992). Similarly, a more recent study performed by Deshmukh et al. (2002) evaluated the influence of body weight on the outcome of TKA surgery. These results showed that body weight did not have an adverse effect on the outcome of TKA in the short-term. Suleiman et al. (2011) mirrored these conclusions and demonstrated no statistical difference in perioperative complication rates in participants undergoing TKA across BMI categories.

Conversely, Silva et al. (2003) conducted a similar study aimed at investigating knee strength following TKA surgery. This study showed that a BMI was associated with relative quadriceps weakness; which may have a negative impact on post-operative function. These results suggested that more thorough rehabilitation after TKA would improve functional outcomes (Silva et al. 2003). Mulhall et al. (2007) investigated the effects of increased weight and BMI on TKA survivorship and on functional

outcomes. The results showed that BMI was a significant predictor of difficulty of function. High weight and BMI has a deleterious effect on the longevity of PTKA, as well as functional and quality of life outcomes following revision TKA. These findings indicated a need for more effective management of these participants (Mulhall et al. 2007).

In conclusion, obesity was not shown to be associated with increased post-operative complications. However, there appears to be some debate over whether overweight and obese participants experience significant post-operative functional deficits and it is suggested that more thorough rehabilitation following TKA surgery would improve functional outcomes in overweight and obese participants.

### **1.2.3 Preoperative Quadriceps Strength And Functional Level**

The level of physical functioning prior to TKA has been said to play an influential role on the recovery process following surgery. Likewise, preoperative quadriceps strength has been shown to be a strong predictor of objective functional measures at one year following surgery (Mizner et al. 2005b). This may be due to the close relation between quadriceps strength and functional outcomes (Stevens et al. 2003), as well as the notable quadriceps strength decline early after surgery (Mizner et al. 2005a). If the preoperative strength and function are poor prior to surgery, and continue to deteriorate post-operatively, we can assume that the functional recovery will be greatly affected.

Lingard et al. (2004) examined the preoperative predictors of pain and functional outcome at one and two years following TKA. They showed that participants with marked functional limitation, prior to the TKA surgery, are predisposed to poor functional outcomes up to two years post-operatively (Lingard et al. 2004). Consequently, the effect of improving physical functioning prior to TKA surgery, as a means of improving post-operative recovery, has been a matter of great interest. Rooks et al. (2006) assessed the effect of a short preoperative exercise intervention on the functional status, pain, and muscle strength of participants before and after TKA. These results showed no significant differences in TKA participants (Rooks et al. 2006). Correspondingly, McKay et al. (2012) examined the effect of a six-week prehabilitation exercise-training programme on pre-surgical quadriceps strength for participants undergoing TKA. This study showed that the intervention elicited clinically meaningful increases in quadriceps strength, walking speed, and mental health immediately before TKA. However the programme did not elicit lasting benefits in the 12-weeks post-surgery. Analysis of these results suggested that quadriceps strength may not determine functional improvements after surgery (McKay et al. 2012).

Topp et al. (2009) performed a similar study, whereby the effects of a preoperative exercise intervention on knee pain, functional ability, and quadriceps strength among participants with knee OA before and after TKA surgery were examined. At the three month post- surgery assessment, the exercise group improved performance on three out of the four functional tasks, decreased all pain measures, and increased quadriceps strength; whereas, the control participants improved their performance on two out of the four functional tasks, decreased all of their pain measures and only

increased their nonsurgical leg strength. These findings indicated the efficacy of pre-rehabilitation among TKA participants (Topp et al. 2009). Lastly, Jagers et al. (2007) examined the effect of a four-week pre-rehabilitation intervention on functional outcomes following TKA surgery. These results suggested that four weeks of pre-rehabilitation had a positive effect on functional task performance and knee proprioception before surgery. After surgery, the intervention group continued to exhibit higher levels of functioning and less pain when compared to the control participants. Thus, they concluded that pre-rehabilitation before TKA surgery may contribute to enhanced recovery following surgery (Jagers et al. 2007).

In conclusion, whilst there is some debate as to the long-term lasting effects of preoperative rehabilitation, existing research indicates that TKA participants that participate in a preoperative rehabilitation intervention show increased improvements in functional performance before surgery and continue to exhibit higher levels of functioning and less pain when compared to the control participants. Therefore, in addition to a post-operative rehabilitation intervention, it is suggested that a preoperative intervention may contribute to enhanced recovery following TKA surgery.

#### **1.2.4 Mental Status**

Poor mental health scores, assessed using the SF-36 questionnaire, have been shown to be associated with poor functional outcome up to two years post-operatively. Lingard et al. (2004) examined the preoperative predictors of pain and functional outcome at one and two year's post-TKA surgery. The conclusions

suggested that the participants who have a discernible low mental health score, prior to TKA surgery, are more likely to have a poorer outcome at one and two years post-operatively.

Vissers et al. (2012) aimed to examine which psychological factors influence the outcome of TKA surgery and to what extent. Strong evidence was found that preoperative depression had no influence on post-operative functioning. In the one-year follow-up, strong indication was found that lower preoperative mental health was associated with lower scores on function and pain. They concluded that low preoperative mental health and pain catastrophizing have an influence on the outcome of TKA surgery (Vissers et al. 2012).

It is unclear whether anxiety and depression before TKA play an influential role in the recovery period following surgery and thus further research is needed to clarify the intricate relationship between mental health status and physical function in participants who undergo TKA.

### **1.2.5 Post-operative Rehabilitation**

Post-operative rehabilitation refers to the rehabilitation interventions participants' may receive, in the immediate and/or future care setting following TKA surgery, in an attempt to return them to everyday ADLs and optimise their physical functioning. Post-operative rehabilitation plays an extremely influential role in determining surgical outcome success and patient satisfaction. This factor will be discussed in detail in the section to follow.

### **1.3 THE EFFECT OF TKA SURGERY ON PHYSICAL AND PSYCHOLOGICAL PARAMETERS**

The TKA is a surgical procedure performed worldwide with the primary goal of reducing pain, restoring physical activity (Ethgen et al. 2004) and improving overall quality of life (QoL) and wellbeing (Marx et al. 2005; Callahan et al. 1994; Fitzgerald et al. 2004; Kane et al. 2005; Kiebzak et al. 2002; Schneider et al. 2004; Jones et al. 2000). Though some participants experience favourable TKA outcomes, such as reductions in their levels of pain and improvements in overall knee function (George et al. 2008; Sloan et al. 2009); one third of participants appeared to be dissatisfied with their operation (Dickstein et al. 1998) and an estimated 15-38% of participants report minimal functional improvements at 12 months post-TKA (Heck et al. 1998; Ayers et al. 2004). There seems to be substantial variance between the objective outcomes and patient satisfaction one year following a standard TKA (Dickstein et al. 1998). The purpose of the following section is to review current research and describe the relevant outcomes related to muscle strength and area, knee function and quality of life following TKA surgery.

#### **1.3.1 Muscle Strength Deficits**

The predominant impairment to function following a TKA is a distinctive reduction in quadriceps strength. The reduction in quadriceps strength, although not fully understood, has been extensively studied and is said to be a result of a number of factors. These include a limitation of post-operative physical activity (Berth et al. 2002; Silva et al. 2003; Walsh et al. 1998; Yoshida et al. 2008), pre-existing

quadriceps weakness associated with OA (Fisher et al. 1991; Lewek et al. 2004; O'Reilly et al. 1998; Slemenda et al. 1997), trauma related to the surgical procedure (Bonutti et al. 2004; Scuderi et al. 2004), and age related limitations of muscle recovery (Forrest et al. 2003; McArdle et al. 2002; Watters et al. 1993). Furthermore, it has been suggested that a combination of muscle atrophy and neuromuscular activation deficits contribute to the residual quadriceps strength improvements (Mizner et al. 2005a). Additionally, the loss of strength in the quadriceps prior to surgery may also be related to a decrease in muscle mass and strength post-TKA. The typical quadriceps cross sectional area of older participants awaiting TKA surgery is approximately two-thirds that of age-matched individuals (Ferri et al. 2003; Frontera et al. 2000; Gür 2002; Gür & Cakin 2003). Within the first month following surgery, a loss of 5-20% of quadriceps mass has been reported (Mizner et al. 2003; Perhonen et al. 1992; Rodgers et al. 1998).

Additionally, a number of research studies have highlighted an inability to fully activate the quadriceps muscles following TKA surgery (Berth et al. 2002; Mizner et al. 2003; Perhonen et al. 1992; Stevens et al. 2003). A widely held belief as to why the patient experiences such quadriceps strength deficits, specifically early after surgery, is that pain associated with the surgery itself induces a diminished capacity to voluntarily activate the muscles. This is commonly known as muscle inhibition. This refers to the inability to fully recruit and activate all the muscle's available motor units, resulting in a decreased or absent muscle contraction (Kent-Braun & Le Blanc 1996). Preliminary studies have confirmed that this reduction in muscle activation is a significant factor contributing to the post-operative muscle weakness (Perhonen et al. 1992; Stevens et al. 2003).

Mizner et al. (2005a) recognised the need for further investigation and headed a study aimed at determining the role of failure of voluntary muscle activation and muscle atrophy in the early loss of quadriceps strength after surgery. 20 participants with unilateral knee OA were tested an average of ten days prior to surgery, as well as 27 days following a primary knee arthroplasty (PTKA). Quadriceps strength, voluntary muscle activation and maximal quadriceps cross-sectional area was measured. The results of this study showed a quadriceps strength loss of 62% post-operatively, as well as a decrease of 10% of maximal cross-sectional area in comparison with the preoperative values. Similarly, voluntary activation was decreased by 17%. The latter, along with muscle atrophy accounted for 85% of the total loss of quadriceps strength (Mizner et al. 2005a). From these results, they concluded that the participants experienced a profound impairment of quadriceps strength one-month post-TKA. This impairment is due largely to an inability to voluntarily activate the muscle, and to a lesser degree, muscle atrophy. Surprisingly, post-operative knee pain played a minor role in the resulting muscle inhibition (Mizner et al. 2005a).

Correspondingly, Meier et al. (2009) studied the long-term contribution of quadriceps muscle activation and muscle volume to impaired muscle strength in older individuals following a TKA. This information was gathered over an average of 21 months following knee surgery. Seventeen individuals, both male and female were required for this study. The age of the participants averaged at  $68 \pm 9$  years with 24 TKA surgeries included in the study. Again, quadriceps strength, voluntary quadriceps muscle activation and quadriceps volume was assessed. The study concluded that quadriceps volume was a much stronger predictor of quadriceps

strength in comparison to muscle activation individuals more than one year following TKA (Meier et al. 2009). Whilst quadriceps activation played a major contributing role in the first few months following TKA, as seen in Mizner et al. (2005), it contributed little to strength one year following TKA. Meier et al. (2009) goes on to suggest that physical rehabilitation interventions aimed at improving muscle size should be considered more relevant as opposed to programmes that focus on addressing neuromuscular activation.

Whilst some researchers have identified some consistent predictors of poor gains in post-operative function, no one participant attribute or surgical factor offers a satisfactory explanation for this outcome variation (Jones et al. 2007). Though the reasoning behind the distinctive reduction in muscle strength following TKA surgery is significant, for the purpose of this review, the impact and reduction of such strength deficits is of greater concern.

A study by Meier et al. (2008) illustrated deficits (>20%) in quadriceps strength and power six months to 13 years post-TKA surgery (Meier et al. 2008). Moreover, the majority of TKA participants reported levels of physical functioning lower than the normative levels of age-matched individuals (Singh & Sloan 2008) and their performance based physical function scores seldom reached those of the control participants (Yoshida et al. 2008). Post-operative walking speeds were up to one third slower (Bolanos et al. 1998); the time required to negotiate stairs was doubled (Walsh et al. 1998) and the distance covered in six minutes was 20% shorter (Moffet et al. 2006) than that of the control participants. It is evident that the reductions in muscle strength post-TKA surgery have a distinct impact on physical functioning and

it has been suggested that improving quadriceps strength may mitigate these impairments and contribute to improved functional outcomes (Meier et al. 2008).

While the resultant quadriceps strength deficits post-TKA surgery have been the focus of most research studies, hamstring strength deficits have also been reported following TKA surgery (Silva et al. 2003; Israelite et al. 1991; Lorentzen et al. 1999; Huang et al. 1996; Mintken et al. 2007); however the focus on the impairments in quadriceps strength is due to the association of the quadriceps to everyday normal functional activities such as walking and climbing stairs (Israelite et al. 1991; Huang et al. 1996; Lorentzen et al. 1999). That being said, it is imperative for both the quadriceps and hamstring muscles to have adequate strength, as well as exist within a precise ratio of one another in order to elicit optimal function. The importance of muscle strength balance surrounding the knee has been emphasised for a number of reasons. One being, that an abnormal muscle strength or muscle imbalances may cause instability within the knee joint, as well as muscle atrophies (Hsieh et al. 1987; Fisher et al. 1991; Israelite et al. 1991; Fisher et al. 1993). Correct co-contraction patterns within the knee are associated with good knee stability. The knee's major movement patterns include flexion and extension; as a result, the muscle strength ratios between the hamstrings and quadriceps are used to understand the muscle changes in the knee (Israelite et al. 1991).

Israelite et al. (1991) evaluated the TKA surgeries using isokinetic testing. This involved testing of both flexion and extension of the knee (primarily quadriceps and hamstring strength) and how these results influenced every day functioning. Isokinetic testing of 68 participants, all with degenerative joint disease, showed that

noticeable muscular strength deficits in both flexion and extension were present prior to TKA surgery in the involved knee. Within the period of seven to 12 months following surgery, hamstring peak-torque values were able to reach that of the uninvolved knee, whereas the quadriceps mechanism continued to show strength deficits at the two-year follow-up evaluation. However, once the quadriceps muscles were rehabilitated, the peak torque ratio of flexion to extension in the involved knee returned to normal levels. Consequently, as the ratio of quadriceps-to-hamstring stabilised, the participant walked with a more symmetrical gait pattern. The authors concluded that a more balanced rehabilitation approach regarding hamstring to quadriceps mechanism is needed for resumption of normal gait (Israelite et al. 1991).

Evidently, muscle strength deficits are predominant following TKA surgery and may have severe negative implications on physical functioning during daily activities. These implications spread far further than the immediate hindrance to physical activity and may impact overall wellbeing and quality of life. Both the hamstring and quadriceps muscles play a vital role in the support and functioning of the knee joint and thus it is vital to find a viable and effective means of addressing any existing muscle strength deficiencies in order to improve physical functioning and overall wellbeing. Some of the offset repercussions of these muscle deficits will be described in the literature to follow.

### **1.3.2 Lean Thigh Volume And Muscle Cross- Sectional Area**

As mentioned previously, TKA surgery has an adverse effect on, primarily; the quadriceps and hamstring muscle strength and that this may be linked to the overall

reduction in actual muscle size. However the extent of the contribution of muscle mass deficits has not yet been fully determined (Perhonen et al. 1992; Stevens et al. 2003). Sarcopenia, defined as the progressive loss of muscle mass with aging, is a fundamental contributor to disability in the elderly population (Volpi et al. 2004). The typical quadriceps cross sectional area of older participants awaiting TKA surgery is approximately two-thirds that of age-matched individuals (Ferri et al. 2003; Frontera et al. 2000; Gür 2002; Gür & Cakin 2003). Within the first month following surgery, a loss of 5-20% of quadriceps mass has been reported (Mizner et al. 2003; Perhonen et al. 1992; Rodgers et al. 1998). It has been said that the failure of the quadriceps muscle activation in participants with OA may be a contributing factor to the muscle atrophy, as a result of neuromuscular inhibition which prevents full muscle activation and potentially blunts the stimulus necessary to maintain muscle mass (Hurley & Newham 1993).

A study utilising magnetic resonance imaging (MRI) assessments on participants awaiting TKA surgery depicts an average quadriceps cross-sectional area (CSA) that is quite small at 42.3 cm<sup>2</sup>. Furthermore, an additional 10% decrease in muscle size one-month following TKA surgery (38.2 cm<sup>2</sup>) in comparison to the preoperative values, has been conveyed (Mizner et al. 2005a). The reduction in muscle mass associated with TKA may be somewhat conservative or minimal when considering the comparisons made between the uninvolved or preoperative values. It is important to note that the assumption that the uninvolved extremity is “normal” may not be a valid when working with individuals with a history of OA. The maximal quadriceps CSA of participants between the ages of 41 to 75 years with a history of OA is 46.1 to 49.5 cm<sup>2</sup> (Gür 2002; Gür & Cakin 2003). The severe effect of the OA

on quadriceps CSA is evident when comparing those measurements to a group of individuals without OA, between the ages of 65 and 81 years, with a maximal CSA of 63.5 to 68.1 cm<sup>2</sup> (Frontera et al. 2000; Ferri et al. 2003). In conclusion, the majority of individuals post-TKA surgery exhibited reduced quadriceps CSA values that are consistent with a history of long term OA- induced weakness (Meier et al. 2008).

Meier et al. (2009) attempted to describe the contribution of quadriceps muscle activation and muscle volume to impaired muscle strength in older individuals an average of 21 months following TKA surgery. 17 individuals were recruited from an orthopaedic surgeon's practice and variable outcomes assessed include quadriceps strength using a maximum voluntary isometric contraction (MVIC), voluntary quadriceps muscle activation (QA) and quadriceps volume (QV). QV was measured using an MRI of the quadriceps. They concluded that quadriceps muscle volume is a much stronger predictor of quadriceps strength as opposed to the muscle activation in individuals more than one year following TKA surgery. However, activation levels made a profound contribution to strength in the first few post-operative months. Rehabilitation measures should consider improving muscle size in this population more relevant than countermeasures addressing the deficits in neuromuscular activation (Meier et al. 2009).

In conclusion, the majority of participants awaiting TKA surgery exhibited reduced quadriceps CSA values, approximately two-thirds that of age-matched individuals, that are consistent with a history of long term OA- induced weakness. However, the reduction in muscle mass associated with TKA may be minimal when making comparisons between the uninvolved limb or preoperative values and it is important

not to assume that the uninvolved limb is “normal” in individuals with a history of OA. That being said, reductions in quadriceps muscle mass appears to be a common consequence of long term OA as well as TKA surgery and may greatly affect an individual’s rate of recovery and ability to perform daily living activities, highlighting the importance of an effective rehabilitation intervention

### **1.3.3 The Sit-To-Stand Transfer**

The sit-to-stand (STS) test is a basic indication of an individual’s ability to rise from a seated position. The typical parameters assessed during the STS test include weight transfer time, force exerted to rise, sway velocity during the rise, as well as symmetry of the rising forces. This action requires a great deal of musculoskeletal, movement and balance control as well as the ability to maintain postural stability. The rising manoeuvre depends greatly on adequate lower extremity strength and range of motion (ROM). Factors hindering these efforts will slow or consequently inhibit one’s ability to rise from a seated position, and of more concern, increase the risk of falls. As previously mentioned, TKA surgery is primarily aimed at reducing pain; however the extent to which this surgery enhances the level of daily functioning is still under debate.

Mizner et al. (2005) hypothesised that quadriceps strength affects performance by altering loading and movement patterns during functional tasks (Mizner & Snyder-Mackler 2005). They assessed 14 unilateral TKA participants with regards to a number of factors, but specifically the STS test. The results showed that during the STS, the participant’s weight shifted away from the involved limb and that the

predominant quadriceps muscle weakness had a significant impact on the movement patterns and performance of the knee during functionally important tasks (Mizner et al. 2005a).

Wang et al. (2006) performed a similar study; however they aimed to investigate the influence of the mechanical differences between a single-radius total knee arthroplasty (SR-TKA) and a multi-radius (MR-TKA) design on the functional performance during the STS movement. The SR TKA group demonstrated enhanced performance with regards to performance time, trunk flexion displacement and velocity, and knee extensor EMG; and greater relative hamstring co-activation. They concluded that the SR TKA provided functional benefits to participants (Wang et al. 2006). Wang et al. (2008) later completed a similar study, where they aimed to compare the biomechanics underlying functional performance of the STS movement between the limbs containing an MR and a SR TKA of bilateral TKA participants. The results showed the SR limb demonstrated greater peak anterior-posterior (AP) ground reaction force, higher AP ground reaction impulse, less vastus lateralis and semitendinosus EMG during the forward-thrust phase of the STS movement and that compensatory adaptations may be used to perform the STS (Wang et al. 2008).

Farquhar et al. (2008) stated that following TKA surgery; although the quadriceps muscle strength and functional test scores show improvement; they continue to be lower than age-matched individuals without injury. An analysis of the STS movement demonstrated differences between limbs in participant's post-TKA, as well as differences between TKA participants and control participants. They hypothesised that participant's one-year post-TKA surgery would show improvements in strength

and movement patterns but would continue to show asymmetries of angles and moments at the hip and knee joints when utilising a self-selected starting position. They recruited 24 participants and each TKA participant was assessed at three months and one-year post surgery. The STS test was analysed using motion capture technology along with EMG and two force platforms. The measurement variables considered included joint angles, muscle activity (EMG), vertical ground reaction forces and functional performance. The results showed that the TKA participants showed improvements in terms of movement, strength and functional performance from three months to one-year post-TKA surgery. However, in comparison to the control participants, the TKA participants used greater hip flexion and a greater hip extensor moment to perform the STS task. They concluded that the increased hip extensor moment suggested that TKA participants may have learned and adopted a compensatory strategy to minimise or evade the use of the quadriceps muscles; however this strategy continued even after the quadriceps muscle strength improved. They proposed that this pattern may be a learned movement pattern that may not be resolved without retraining (Farquhar et al. 2008).

Farquhar et al. (2009) then went on to investigate the dissimilarities between self-selecting or constraining position with regards to the STS movement. Twenty-six participants with unilateral TKA were initially asked to perform the STS using a self-selected position. Trials were then collected in a constrained condition STS where both knees were positioned with the tibia vertical i.e. perpendicular to the floor. The results showed that the test participants used greater hip flexion bilaterally during the constrained condition STS ( $91^\circ$ ) in comparison to the self-selected STS ( $87^\circ$ ). Similarly, knee flexion on the non-operated limb was greater during self-selected

STS (84°) when compared to the constrained condition STS (82°). Both these results were significant. Finally, the constrained condition STS resulted in larger extensor moments on the non-operated limb at the hip and knee when compared to the operated limb. Thus, the constrained condition exacerbated the asymmetries at the hip and knee and did not improve mobility of the operated limb. Farquhar et al. (2009) suggests that this reliance on the non-operated limb may increase the risk for progression of OA in other joints of the lower extremities. Subsequently, TKA surgery has the potential to negatively alter one's ability to rise from a seated position, which, in itself, has far reaching consequences on daily living activities and even QoL.

#### **1.3.4 Quality Of Life And Patient Satisfaction**

As previously mentioned, we see that TKA surgery is a common and often reliable solution for the treatment of debilitating OA and other knee related disabilities and allows TKA participants to a large extent regain their physical function (Ethgen et al. 2004), reduces pain and improves their QoL (Jones et al. 2000; Marx et al. 2005; Fitzgerald et al. 2004; Kiebzak et al. 2002; Schneider et al. 2004; Callahan et al. 1994). A meta-analysis of 130 studies indicated that these favourable results continue over time (Callahan et al. 1994). However, despite these favourable results, not all participants express satisfaction following surgery. The primary complaint leading to dissatisfaction following surgery appears to be that of suboptimal physical functioning, often resulting in decreased social functioning and reductions in QoL.

Dickstein et al. (1998) strived to assess participants' self-appraisal of their TKA surgery, six and 12 months post-operatively, and to establish which factors determine dissatisfaction with the surgery. The study group consisted of 79 participants subjected to TKA surgery and the data was collected by use of personal interviews and physical examinations. The results of the one-year follow-up indicated a decrease in the prevalence of pain in the post-operated knee and improvement in ambulatory capacities. However, one third of the respondents continued to express dissatisfaction from the operation. Dickstein et al. (1998) suggested that this dissatisfaction could have resulted from inappropriate expectations from either misinterpretations or limited prior knowledge of the likely results of the operation (Dickstein et al. 1998).

Jones et al. (2000) aimed to quantify the magnitude of change seen with QoL outcomes six months after TKA and total hip arthroplasty (THA). Health related quality of life (HRQoL) measures were evaluated with the Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index and the Medical Outcome Survey Short Form SF-36 (Jones et al. 2000). The results indicated that health dimensions such as social function, bodily pain, physical function, vitality, and general health showed significant improvement after surgery. Psychosocial dimensions with modest changes had baseline values comparable to age and sex adjusted normative values; whereas, bodily pain and physical function, which had large changes, had values lower than the normative levels. 77% of participants were satisfied with their TKA surgery. Large improvements were reported for pain and function after joint arthroplasties, while small to moderate changes were seen in other areas related to QoL (Jones et al. 2000).

Bullens et al. (2001) investigated patient satisfaction following TKA surgery by comparing subjective and objective outcome measures. They used a visual analogue scale (VAS) to assess the satisfaction after TKA surgery in a group of 108 participants, as well as Knee Society Scores (KSS), the WOMAC index, a pain VAS, and lastly a survival analysis. When comparing the subjective to the objective measures, only poor correlations were showed. They suggested that in comparison to the desired outcomes of the participants, the orthopaedic surgeons priorities might differ. Interestingly though; the satisfaction VAS showed a significantly better subjective outcome in rheumatoid arthritis participants post-operatively when compared with OA participants, however; the KSS were similar (Bullens et al. 2001).

Kiebzak et al. (2002) aimed to document the disease burden of OA and the benefits of total joint replacement by using the SF-36 general health status survey and evaluate other factors that could affect scores. All participants' scheduled for TKA and THA surgery in the next two years were surveyed using the SF-36, which assessed HRQoL in participants' physical and social functioning, as well as mental health. Follow-up surveys were administered 12 months after surgery to all participants and at three and 24 months after surgery to a subset of participants (Kiebzak et al. 2002). The results showed that prior to surgery; participant scores were significantly lower than normative scores in the physical functioning, bodily pain, and social functioning domains. Preoperative scores were not different between THA and TKA participants. Women typically scored lower than men and comorbid conditions were faintly associated with low SF-36 scores. Following surgery, the largest incremental improvement in scores was seen at the three-month follow-up. Scores improved sooner and more substantially in THA when compared to

TKA participants and were greater in men in comparison to women. In conclusion, the SF-36 has the sensitivity to document improvement in HRQoL after surgery; however, routine use of outcome assessment instruments to monitor this patient population may be costly and unwarranted (Kiebzak et al. 2002).

TKA surgery, as well as THA surgery, is accepted as a reliable and suitable surgical procedure to return participants to function. HRQoL instruments have been used to document outcomes in participants following TKA surgery as a means of optimising the allocation of resources to promote and enhance recovery (Ethgen et al. 2004). Ethgen et al. (2004) study reviewed the literature regarding the outcomes of total hip and knee arthroplasties as evaluated by HRQoL instruments. They reviewed 74 studies, of which 32 investigated total hip and total knee arthroplasties, 26 focused on THA, and 16 focused on TKA exclusively. The SF-36 and the WOMAC index were the most frequently used instruments. Overall, the results showed that both TKA and THA surgery was found to be quite effective in terms of improvement in HRQoL dimensions, with the occasional exception with regards to the social dimension. Age was not found to be detrimental to effective surgery and men seemed to benefit more from the surgical intervention when compared to women. When improvement was found to be modest, the existence and role of comorbidities was highlighted and participants who had inferior preoperative HRQoL were more likely to experience greater improvements following surgery (Ethgen et al. 2004).

Similarly, Singh et al. (2008) studied the HRQoL in veterans following TKA and THA surgery and then compared these individuals to the age- and gender-matched USA population, as well as the control veteran population without these surgical

procedures (Singh & Sloan 2008). The outcome measure used for this study was the SF-36. They concluded that profound physical HRQoL deficits exist in veterans following TKA/THA surgery in comparison to the age- and gender-matched general USA population and veteran controls. These deficits were not attributable to differences in socio-demographics, comorbidity and/or healthcare access and utilisation. Singh et al. (2008) proposed that future studies are needed to determine HRQoL deficit causes as well as the interventions to improve these deficits (Singh & Sloan 2008).

In conclusion, whilst improvements for pain and function following TKA surgery are reported, only small to moderate changes were seen in other areas related to QoL and despite these favourable functional outcomes, not all participants express satisfaction following surgery. The primary complaint resulting in dissatisfaction post-TKA appears to be related to suboptimal physical functioning, often resulting in decreased social functioning and reductions in QoL. It has been suggested that this dissatisfaction may be a result of misunderstandings or insufficient knowledge prior to surgery that lead to inappropriate expectations of the outcome of TKA surgery (Dickstein et al. 1998).

## **1.4 REHABILITATION**

Post-operative rehabilitation is a major determining factor for surgical outcome success, post-operative physical functioning and overall patient satisfaction and QoL. Rehabilitation related to TKA surgery will be discussed in detail in the following section.

### **1.4.1 What Is The Role Of TKA Rehabilitation**

As mentioned previously, TKA surgery may bring about great improvements in the participants self-reported levels of pain; however these individuals are often plagued with predominant quadriceps muscle impairments and functional limitations (Meier et al. 2008). Failure to adequately address this chronic muscle weakness has the potential to limit the long-term functional gains that may be possible following TKA. Post-operative rehabilitation addressing quadriceps strength should mitigate these impairments and ultimately result in improved functional outcomes (Meier et al. 2008). Numerous studies have attempted to identify the benefits of a rehabilitation intervention following TKA, some of which will be discussed below.

Barrois et al. (2007) aimed to identify what the role of the physical medicine and rehabilitation unit is following TKA surgery. They conducted a study in order to develop clinical practice guidelines concerning the interest of post-operative rehabilitation in the physical medicine and functional rehabilitation (PMR) ward after TKA. The outcomes measured included impairment, disability, medico-economic implications and post-operative complications. Their results showed that post-

operative rehabilitation in a PMR ward after TKA could reduce the LOHS in a surgical ward and increase the functional status of participants with comorbidities (Barrois et al. 2007).

Minns Lowe et al. (2007) conducted a systematic review of data in order to evaluate the effectiveness of physiotherapy exercise after elective PTKA in participants with osteoarthritis. The outcomes measured included functional ADLs, walking or gait, QoL, muscle strength, and ROM in the knee joint. The results indicated that interventions including physiotherapy functional exercises after discharge result in short term benefit after elective PTKA. Unfortunately, the effect sizes were too small to moderate, with no long term benefit (Minns Lowe et al. 2007).

Conversely, Rajan et al. (2004) conducted a similar study to determine the effectiveness of physiotherapy on post-TKA participants. They performed a prospective randomised controlled trial, whereby two groups were randomised to receive or not receive outpatient physiotherapy following TKA. Their findings showed no statistically significant benefit of outpatient physiotherapy at any of the three times measured. They concluded however; that in a preselected group of participants following PTKA, inpatient physiotherapy with good instructions and a well-structured home exercise regime can dispense with the need for outpatient physiotherapy (Rajan et al. 2004).

Evidently, there are a number of potential benefits post-operative rehabilitation can achieve and thus, is it highly recommended that each patient participate in some or other form of post-surgery physical therapy. Although it has been determined that

post-operative rehabilitation is beneficial following TKA, it is not yet known what the optimal treatment entails. Many studies have attempted to identify the most effective approach to this post-operative rehabilitation and the section to follow is aimed at summarising these research findings.

### **1.4.2 Types Of TKA Rehabilitation**

As previously mentioned, a variety of studies have been conducted in an attempt to determine which rehabilitation approach elicits the maximum benefits. For the purpose of this study, the predominant methods implemented will be discussed.

#### **1.4.2.1 Standard Rehabilitation**

Improvements in daily functioning and thus QoL typically relate to increases in muscle strength and overall stability. These gains in strength occur when a muscle produces a force. If the muscle shortens during the contraction it is defined as a concentric muscle contraction, whereas, if the muscle lengthens during muscle contraction it is defined as an eccentric muscle contraction (LaStayo et al. 2000).

End-phase standard care physical therapy, following TKA surgery, characteristically employs the use of concentric exercises in an attempt to reduce the post-operative muscle deficits. These exercise programmes may be implemented in either a hospital setting or at an independent rehabilitation facility. Alternatively, a home-based exercise programme may be provided for the participants. It has been suggested that home-based rehabilitation interventions may have limitations;

however, post-operative rehabilitation can be extremely costly and may not be feasible for all participants. Standard care rehabilitation implemented following TKA surgery typically encompasses a progressive three-phase exercise programme. This exercise programme is aimed at reducing post-operative pain levels and enhancing knee ROM, muscular strength, ADLs and HRQoL (Meier et al. 2008; Moffet et al. 2006; Minns Lowe et al. 2007; LaStayo et al. 2000).

In order to increase knee flexion ROM, continuous passive movement (CPM) exercises are often employed to encourage movement within the knee. Snyder et al. (2004) conducted a study aimed at comparing the rehabilitation methods used for participants recovering from TKA. The rehabilitation programme included isometric exercises of the muscles in the operated joint, general fitness exercises in bed, and passive exercises of the knee conducted by a physiotherapist. They concluded that introducing CPM into TKA post-operative rehabilitation accelerates the participants' progress and reduces hospitalisation time. This then has the potential to indirectly positively influence the participants' emotional wellbeing and perception of QoL and enables a faster return to ADLs (Synder et al. 2004).

Kramer et al. (2003) conducted a study to compare a clinic- and home-based rehabilitation programmes following TKA. The clinic-based rehabilitation intervention was implemented by outpatient physical therapists; whilst the home-based rehabilitation was monitored by periodic telephone calls from a physical therapist. Both rehabilitation interventions emphasised a common home exercise programme. The findings of this study showed that, following TKA surgery, participants who completed the home-based rehabilitation intervention performed similarly to the

participants who completed regular outpatient clinic sessions in addition to the home exercises (Kramer et al. 2003). This may serve as a viable alternative to inpatient rehabilitation for those participants who are unable to afford or attend such therapy.

In summary, although clinic- and home-based standardised exercise programmes may be limited in terms of individualisation and progression, they have been shown to increase speed of recovery, decrease hospitalisation time and aid in the restoration of knee ROM.

#### **1.4.2.2 Fast Track Rehabilitation**

"Fast-track" rehabilitation is a multimodal perioperative treatment concept for accelerating post-operative recovery (Gregor et al. 2008), which has been implemented following a variety of surgical procedures, including TKA surgery.

Holm et al. (2010) investigated the relationship between early functional mobility and pain intensity in a fast track programme following TKA surgery. The results showed that on the first post-operative day, 90% of the participants were able to walk independently with median pain intensity. All participants walked independently on post-operative day two with median pain intensity, median ROM, median test time of the timed-up-and-go test (TUG), as well as a median LOHS of three days. They concluded that pain had a limited influence on the functional recovery beyond the first post-operative day after TKA, thereby allowing early physiotherapy (Holm et al. 2010).

Similarly, Den Hertog et al. (2012) investigated fast-track rehabilitation concept in terms of a measurable effect on the early recovery after TKA surgery. The cumulative AKSS questionnaire was the primary evaluation variable, used to detect changes in both joint functioning and the participants perception of pain. The secondary evaluation variables included the WOMAC index score, analgesic drug consumption, LOHS, and safety. The findings indicated that participants in the fast-track rehabilitation group showed significantly enhanced recovery, when compared with the participants in the standard rehabilitation group, based on the differences between the groups for the cumulative AKSS, WOMAC index score, reduced intake of concomitant analgesic drugs, reduced LOHS, as well as a lower number of adverse events. They concluded that, following TKA surgery, implementation of pathway-controlled fast-track rehabilitation is achievable and decidedly beneficial (Den Hertog et al. 2012).

Lastly, Bandholm et al. (2012) conducted a study titled “Physiotherapy exercise after fast-track total hip and knee arthroplasty: time for reconsideration?” They showed that the latest meta-analyses on the effectiveness of physiotherapy exercise following THA and TKA generally conclude that physiotherapy exercise after TJA is not very effective or does not work. They suggested the reason for this might be that the mode of physiotherapy exercise typically offered after TJA does not contain the right components, such as little intensity, or is offered at the wrong time i.e. too late after surgery. They proposed changing the focus to earlier-initiated and more intensive physiotherapy exercise after TJA, such as fast track rehabilitation, in order to reduce the early loss of muscle strength and function after surgery. Lastly, they recommended that ideally, the physiotherapy exercise interventions should be

simple, using few and well-chosen exercises that are described in detail, adhering to basic exercise physiology principles where possible (Bandholm & Kehlet 2012).

In conclusion, pain was not a limiting factor on the functional recovery beyond the first post-operative day after TKA surgery, thereby allowing early physiotherapy. Additionally, physiotherapy and rehabilitation initiated early after TKA surgery and at higher intensities resulted in significantly enhanced recovery and reduces early loss of muscle strength and function following surgery.

#### **1.4.2.3 Rehabilitation Using Neuromuscular Electrical Stimulation**

Neuromuscular electrical stimulation (NMES) employs the use of an electrical stimulus to a group of muscles, most commonly as a form of muscle rehabilitation. This technique is primarily used by physical therapists in order to treat injury, stroke participants, or incidents that result in the loss of muscle function. Lack of neural innervation due to neurological damage renders muscle unable to produce force. Thus, NMES is applied in an attempt to restore movement and the ability to perform ADLs (Doucet et al. 2012). This is achieved by passing an electrical impulse from a device through electrodes placed on the skin over the targeted muscle or muscles.

Following TKA surgery, restoration of preoperative or norm based quadriceps muscle function; in most cases, is rare. Mintken et al. (2007) proposed that early application of NMES offers a possible solution in an attempt to minimise loss of quadriceps torque more effectively than traditional rehabilitation exercises alone. They conducted a study that employed the use of early NMES to optimise

quadriceps muscle function following TKA. The study outcomes showed that, at three, six, and 12 weeks after TKA, quadriceps torque was greater than the preoperative values of the involved side by 16%, 29%, and 56%, respectively. Similarly, muscle activation improved to 93.4%, 94.6%, and 93.5% at three, six, and 12 weeks after TKA. They showed that, despite presenting preoperatively with substantial quadriceps torque and activation deficits, the participant in this case demonstrated improvements in quadriceps function at all the times measured. Therefore, mitigating quadriceps muscle weakness immediately after TKA using early NMES may improve functional outcomes (Mintken et al. 2007).

Avramidis et al. (2003) investigated the possible effect of electric muscle stimulation (EMS) of the vastus medialis on the walking speed, Hospital for Special Surgery (HSS) knee score, and Physiological Cost Index (PCI) of participants during rehabilitation after TKA. The main outcome observed changes in walking speed; HSS knee score, and effort of walking as measured by the PCI. The increase in walking speed was statically significant; however, no statistically significant difference was observed in relation to the PCI or the HSS knee score variables (Avramidis et al. 2003).

Similarly, a more recent study by Stevens-Lapsley et al. (2012) investigated the effect of early NMES to improve quadriceps muscle strength following TKA surgery. Participants were randomly assigned to receive standard rehabilitation (control) or standard rehabilitation plus NMES applied to the quadriceps muscle, initiated 48 hours after surgery. The NMES was applied twice per day at the maximum tolerable intensity for 15 contractions. At 3.5 weeks after TKA, significant improvements with

NMES were found for quadriceps and hamstring muscle strength, functional performance, and knee extension active range of motion. At 52 weeks, the differences between groups were reduced, but improvements with NMES were still significant for quadriceps and hamstring muscle strength, functional performance, and some self-report measures. They concluded that the early addition of NMES effectively attenuated loss of quadriceps muscle strength and improved functional performance following TKA (Stevens-Lapsley et al. 2012).

In conclusion, the addition of early neuromuscular electrical stimulation is shown to increase quadriceps and hamstring strength, increase-walking speed, improve functional performance and self-report measures immediately after TKA surgery.

#### **1.4.2.4 Eccentric Rehabilitation**

As previously mentioned, gains in strength occur when a muscle produces a force and there are different ways in which the muscle may contract. Concentric muscle contractions involve the shortening of the muscle fibres, whilst the muscle lengthens during eccentric contractions (LaStayo et al. 2000). Research suggests that eccentric muscle contractions may elicit superior developments in strength gains and may produce two to three times the force production of a typical isometric or concentric muscle contractions (Lindstedt et al. 2001). In addition to this proposed enhanced force production, eccentric muscle contractions require less metabolic cost or a reduced oxygen requirement when compared to a concentric muscle contraction (Abbott et al. 1952; Bigland-Ritchie & Woods 1976). Similarly, eccentric muscle activity has been shown to be largely fatigue resistant (Kay et al. 2000).

A study performed by Higbie et al. (1996) compared the effects of concentric and eccentric isokinetic training on quadriceps muscle strength, cross-sectional area, and neural activation in women aged 20 ( $\pm 1$ ) years. These results showed that eccentric isokinetic training is more effective when developing strength in eccentric isokinetic muscle actions and that concentric isokinetic training is more effective when developing strength in concentric isokinetic muscle actions. They concluded that gains in strength consequent to concentric and eccentric training are highly dependent on the muscle action used for training and testing (Higbie et al. 1996). These findings are mimicked in numerous research studies comparing concentric and eccentric isokinetic training.

A systematic review with meta-analysis conducted by Roig et al. (2009) investigated the effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults. The aim of this systematic review was to determine if eccentric exercise is superior to concentric exercise in stimulating gains in muscle strength and mass. The results of a subgroup analyses in which intensity was equated as a percentage of one repetition of maximal effort (1RM) during concentric training showed no major differences between eccentric and concentric training in promoting gains in strength. In contrast, eccentric training performed at high intensities was more effective in promoting increases in muscle mass measured as muscle girth. In addition, eccentric training also showed a trend towards increased CSA measured with MRI or computerised tomography (CT). However, strength gains after eccentric training are highly specific to the mode of contraction and velocity of movement (Roig et al. 2009). They suggested that further research is required to investigate the underlying mechanisms of this specificity and its functional

significance in terms of transferability of strength gains to more complex human movements (MacLean et al. 2009).

Likewise, Gür et al. (2002) conducted a study aimed at comparing the effects of concentric and coupled concentric-eccentric isokinetic resistance training on functional capacity and symptoms of participants with OA of both knees. The results showed that both training groups showed marked decreases in pain scores and increases in functional capacity together with increases in peak torque and CSA of knee muscles. The results indicated that concentric-eccentric training had a greater influence on functional capacity, especially stair climbing and descending, however, the improvements in pain measurements were better in the concentric group compared with the concentric- eccentric group after the training (Gür 2002).

The research available on eccentric rehabilitation following TKA surgery is somewhat limited; however studies do exist indicating the potential benefits of this mode of physical therapy. A clinical study conducted by Marcus et al. (2011) investigating the effects of an eccentrically-biased rehabilitation intervention early after TKA contributed to the growing evidence promoting the potential benefits of negative work based rehabilitation. The results of this study showed that individuals in the eccentric intervention group showed improvements in the primary physical function endpoints; namely, the SF-36 and the six-minute walk test (6MWT), as well as improvements in muscle function endpoints, such as knee extension strength and power. They concluded that eccentrically-biased exercise used as an addition to rehabilitation may help amplify and accelerate physical function following TKA surgery (Marcus et al. 2011).

Further research has been conducted investigating the effects of eccentric rehabilitation following other injuries and musculoskeletal conditions. For instance, Gerber et al. (2007) conducted a study to investigate the effects of early progressive eccentric exercise on muscle structure after anterior cruciate ligament (ACL) reconstruction. The results showed that volume and peak CSA of the quadriceps and gluteus maximus, in both the involved and the uninvolved thighs and in the participants treated with each type of graft, improved significantly more in the eccentric exercise group. The magnitude of the volume change was more than twofold greater in that group. They concluded that eccentric resistance training implemented three weeks after reconstruction of the ACL can induce structural changes in the quadriceps and gluteus maximus that greatly exceed those achieved with a standard rehabilitation protocol (Gerber et al. 2007).

## 1.5 OVERVIEW

As the above mentioned research suggests, eccentric muscle contractions may elicit superior developments in both eccentric and overall strength gains and may produce two to three times the force production of a typical isometric or concentric muscle contractions (Lindstedt et al. 2001; Roig et al. 2009). Similarly, research investigating the physiological response to a single bout of eccentric cycling shows that when eccentric and concentric cycling are matched in terms of oxygen consumption, eccentric cycling produces greater force in comparison to concentric cycling (Perrey et al., 2001; Dufour et al., 2004; Dufour et al., 2006). Therefore, eccentric cycling rehabilitation may be an effective means to offset existing muscle strength deficits and enhance overall physical functioning following TKA surgery.

Additionally, due to the propensity for TKA patients to be of older age, the existence of comorbidities is a factor to consider, especially possible limitations of the cardiovascular system. Research has shown that when eccentric and concentric cycling is matched in terms of force production; oxygen consumption, heart rate and muscle activation are significantly lower during eccentric cycling when compared with concentric cycling (Bigland-Ritchie et al., 1973; Dufour et al., 2004; Dufour et al., 2006). Therefore, as eccentric cycling can produce a greater force with a reduced cardiac demand and lower perception of exertion levels, it is an ideal therapeutic modality in cases where physical capacity is limited, such as following TKA surgery.

With more than 500,000 TKA surgeries performed each year in the United States of America, with the expected number to increase by more than 600% to approximately 3.5 million surgical procedures by the year 2030 (Kurtz et al. 2007), it is of vital importance to find an efficient means to offset TKA related disability and poor physical functioning. A study conducted by Ruiz et al. (2013) investigated the estimated value of TKA surgery from a societal perspective, including the costs and benefits related to the patient, the employers and the person responsible for financing the surgery. They concluded that the estimated lifetime societal savings gained from over 600,000 TKA surgeries performed in the USA in 2009 were estimated to be approximately \$12 billion. The patients and employers were the primarily beneficiaries of these societal savings, with 85% of these savings originating from increased employment and earnings and a further 15% from a reduction in the days of work missed and disability payments (Ruiz et al. 2013). This study demonstrated the importance of a societal perspective when considering the costs and benefits of TKA surgery as well as the importance behind establishing an effective therapeutic modality that will allow for a prompt recovery and return to work.

Despite the large amount of research highlighting the advantages of eccentric rehabilitation, and specifically eccentric cycling, the typical standardised rehabilitation protocol following a TKA consists of home based concentric exercises, most of which have reported less than favourable results. Additionally, although eccentric training seems to be an effective means of restoring knee function, no study, to our knowledge has compared eccentric to concentric training rehabilitation intervention, which are matched in duration and perceived exertion. Consequently, the need for further research has become evident.

Thus, the purpose of this thesis is to investigate and compare the effects of an eccentric versus concentric cycling ergometry protocol for TKA rehabilitation, utilising the Grucox Cycle Ergometer, on muscle strength and activation, lean thigh volume, levels of physical activity, functional ability utilising the STS test and finally HRQoL parameters, in order to determine which therapeutic modality is the most effective in enhancing overall knee and physical functioning and quality of life.



## CHAPTER 2

### AIMS AND OBJECTIVES

#### 2.1 PURPOSE OF RESEARCH

The TKA is a reliable surgical procedure with the goal of enabling patients to regain physical activity (Ethgen et al. 2004), reducing pain and improving quality of life (QoL) (Marx et al. 2005; Callahan et al. 1994; Fitzgerald et al. 2004; Kane et al. 2005; Kiebzak et al. 2002; Schneider et al. 2004; Jones et al. 2000). However, whilst some patients experience successful reductions in their levels of pain and improvements in overall knee function (George et al. 2008; Sloan et al. 2009); more than one-third of the patients experience suboptimal physical function following TKA surgery (Jones et al. 2000; Franklin et al. 2008; Brander et al. 2003; Dickstein et al. 1998). It has been suggested that the predominant impairment to function following a TKA is a distinctive reduction in quadriceps strength that has been associated with a limitation of post-operative physical activity (Berth et al. 2002; Silva et al. 2003; Walsh et al. 1998; Yoshida et al. 2008) and thus, addressing this problem may serve as a means to eradicate these physical deficiencies and contribute to improved functional outcomes.

Research suggests that eccentric muscle contractions may elicit superior developments in strength gains and physical functioning and may be an ideal therapeutic modality where functional activity is limited, as in the case of TKA surgery (Lindstedt et al. 2001). However, despite the abundance of research highlighting the

advantages of eccentric rehabilitation, the typical standardised rehabilitation protocol following a total knee replacement consists of home based concentric exercises, most of which have reported less than favourable results. Consequently, the need for further research has become evident.

The primary purpose of this thesis is to identify and compare the effects of an eccentric versus concentric rehabilitation intervention, matched in both duration and perceived exertion, in order to identify which modality is the most feasible and effective in restoring functional ability in participants as early as three months post-TKA.

## **2.2 RESEARCH STUDY AIMS**

Due to the large amount of data collected during this thesis, the results were presented in four separate studies, however the same participants were used throughout the data collection period. This was simply a means to present the results in a way that is easy to follow and understand.

### **2.1.1 Study 1**

Study 1 investigates the feasibility of an eccentric rehabilitation intervention in comparison to a concentric rehabilitation intervention in participants as early as three months post-TKA. The primary objectives and hypotheses of the first study are as follows:

- \* To determine if an eccentric rehabilitation intervention is feasible with regards to levels of pain or discomfort when compared to a concentric rehabilitation intervention, matched in duration and perceived exertion, in participant's as early as three months post-TKA. The hypothesis is that both the eccentric and concentric rehabilitation interventions will be well tolerated in the TKA population.
  
- \* To investigate if an eccentric rehabilitation intervention elicits a reduced heart rate in comparison to the concentric rehabilitation intervention, matched in duration and perceived exertion, in participant's as early as three months post-TKA. The hypothesis is that the heart rate of the eccentric group will be

significantly lower during the rehabilitation intervention when compared with the concentric group.

- \* To investigate if an eccentric cycling rehabilitation intervention elicits superior power and work output over the course of eight-weeks, in comparison to the concentric rehabilitation intervention matched in duration and perceived exertion, in participants as early as three months post-TKA. The hypothesis is that the power and work output of the eccentric group will be significantly greater than that of the concentric group during the rehabilitation intervention.

### **2.1.2 Study 2**

Study 2 investigates the effects of an eccentric rehabilitation intervention in comparison to a concentric rehabilitation intervention on muscle strength, endurance, muscle activity and muscle area in participants as early as three months post-TKA.

The primary objectives and hypotheses of the second study include:

- \* To establish if the eccentric rehabilitation intervention produces greater increases in quadriceps and hamstring muscular strength outputs, as measured using the Biodex Isokinetic Dynamometer, in comparison to the concentric rehabilitation intervention. Additionally, if the rehabilitation interventions result in increased quadriceps and hamstring muscular strength and endurance from the pre- to post-intervention measurements respectively. The hypothesis is that the eccentric rehabilitation intervention will produce greater increases in quadriceps and hamstring muscular strength outputs, as

measured using the Biodex Isokinetic Dynamometer, in comparison to the concentric rehabilitation intervention.

- \* To determine if the eccentric rehabilitation intervention produces greater increases in lower limb muscle volume compared to the concentric rehabilitation intervention. Additionally, if the rehabilitation interventions result in increases in lower limb muscle volume, from the pre- to post-intervention measurements respectively. The hypothesis is that the eccentric rehabilitation intervention will produce greater increases in lower limb muscle volume compared to the concentric rehabilitation intervention.
  
- \* To identify any variations in muscle activity (EMG) of the vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) muscles during the isokinetic testing between the eccentric and concentric exercise participants. The hypothesis is that the eccentric rehabilitation intervention will result in greater reductions in muscle activity of the vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) muscles in comparison to the concentric rehabilitation intervention.

### **2.1.3 Study 3**

Study 3 investigates the effect of an eccentric cycling ergometry rehabilitation intervention in comparison to a concentric cycling ergometry rehabilitation intervention on self-report physical and mental health surveys in participants as early

as three months post-TKA. The main objectives and hypotheses of the third study are as follows:

- \* To determine if an eccentric cycling exercise rehabilitation intervention produces greater improvements in knee function, as measured by validated knee scores and assessments, when compared to the concentric rehabilitation intervention. Namely; the Knee Injury and Osteoarthritis Outcome Score (KOOS) and the Tegner Level of Activity Scale. Additionally, to determine if the rehabilitation interventions result in improvements in knee function, as measured by validated knee scores and assessments, from the pre- to post-intervention measurements respectively. The hypothesis is that the eccentric rehabilitation intervention will produce greater improvements in knee function, as measured by validated knee scores and assessments, when compared to the concentric rehabilitation intervention
  
- \* To determine if an eccentric cycling rehabilitation intervention produces greater enhancements to the perception of overall wellbeing and quality of life, as measured by a validated self-report based health questionnaire, in comparison to the concentric rehabilitation intervention. Namely, the SF-36 Health Survey. Additionally, to determine if the rehabilitation interventions result in improvements in knee function, as measured by validated knee scores and assessments, from the pre- to post-intervention measurements respectively. The hypothesis is that the eccentric rehabilitation intervention will produce greater enhancements to the perception of overall wellbeing and

quality of life, as measured by a validated self-report based health questionnaire, in comparison to the concentric rehabilitation intervention.

#### **2.1.4 Study 4**

The primary purpose of study 4 was to describe and compare the STS transfer using joint kinematic, ground reaction force and muscle activity outcomes in participant's as early as three months post-TKA surgery randomised into a concentrically or eccentrically biased rehabilitation intervention. As study 4 was an exploratory study, there is no precise hypothesis stated and it is purely a tentative investigation. However, the principal objectives of the fourth study comprise the following:

- \* To describe and compare joint kinematic and ground reaction force outcomes during the sit-to-stand transfer, from pre- to post-intervention between the eccentric and the concentric rehabilitation intervention groups. The hypothesis is that the eccentric rehabilitation intervention will result in greater
- \* To describe and compare the muscle activity (EMG) of the vastus medialis, vastus lateralis and biceps femoris muscles during the sit-to-stand transfer between the eccentric and concentric rehabilitation interventions.
- \* To describe and compare the effect of the rehabilitation interventions on weight transference to the uninvolved limb during the sit-to-stand transfer.



## CHAPTER 3

### METHODOLOGY

#### 3.1 STUDY DESIGN

##### 3.1.1 Overview Of Trial Procedures

Approval from the Human Research Ethics Committee (HREC) was granted prior to the commencement of any research activities (HREC reference number: 101/2012). All participants voluntarily signed an informed consent form (Appendix A) prior to enrolment. Once the participants were enrolled, they were randomised into either the eccentric (ECC) or concentric (CON) intervention group, without knowledge of which group they were assigned to (single blind). The participants were also required to complete a medical history questionnaire (Appendix B) and a physical activity readiness questionnaire (PARQ) (Appendix C). The baseline and post-intervention assessments or outcome variables included a variety of validated measures. These consisted of measures of physical activity, such as the Tegner Activity Level Scale, the global SF-36 Health Survey, as well as measures of functional capacity, such as the Knee Injury and Osteoarthritis Outcome score (KOOS), and a sit-to-stand transfer analysis and isokinetic strength testing. In addition to the abovementioned outcomes, all participants' quadriceps muscle volume was calculated.

Electromyography (EMG) was recorded during the isokinetic strength assessment and the sit-to-stand transfer. The pre-intervention assessments as well as a familiarisation test performed on the Biodex Isokinetic Dynamometer machine (isokinetic strength assessment testing) were conducted within one week prior to the commencement of the rehabilitation protocol. The post-intervention testing took place after a four to eight day resting period following the final session at the end of the eight-week rehabilitation protocol.

Both the eccentric (n=9) and concentric (n=9) intervention groups were required to complete the cycle ergometry rehabilitation intervention. All participants completed a progressive rehabilitation intervention on the Grucor Rehabilitation Cycle that consisted of three exercise sessions a week for a period of eight weeks (n=24). During each exercise session, participants performed a 20-minute cycling protocol that focused on either eccentric or concentric cycling ergometry. The specific intervention is outlined below.

The investigators directing the study were responsible for conducting the exercise session as well as the pre and post outcome assessments; thus, it was not possible to blind the investigators on this study. That being said, the outcome variables measured during the exercise sessions, such as rate of perceived exertion (RPE) and heart rate (HR), were recorded and are objective measures of performance. The possibility of having independent assessors was discussed, however due to limitations of personnel and the cost implication, this was not feasible. In order to minimise inter-investigator variability, the same investigator was responsible for

specific measurements throughout the data collection and a set protocol was followed each time, as described in section 3.2 to follow.

### **3.1.2 Recruitment**

Participants who had undergone unilateral TKA surgery at the Sports Science Orthopaedic Clinic in the preceding three to nine months were identified and recommended to Dr Willem van der Merwe and Dr Hayden Hobbs. These specialists, as well as the investigators, were involved in the confirmation of the inclusion and exclusion criteria. All participants voluntarily signed an informed consent form (Appendix A) prior to enrolment. Thereafter, the physicians conducted a medical screening to ensure all participants were able to safely perform exercise and were cleared for participation in the study. Participants that surpassed these safety measures were referred again to the knee orthopaedic surgeon, Dr Willem van Der Merwe, for a full knee examination.

The investigators contacted the participants that had been cleared on all criteria and arranged a face-to-face meeting in order to describe the study in detail and allow the participants to ask any outstanding questions. A total of 21 participants who had undergone unilateral TKA surgery in the preceding three to nine months were successfully recruited for this randomised, single blinded, control trial. All inclusion and exclusion criteria were met as described below (section 3.1.2.1 and 3.1.2.2). Of the total 21 individuals, 18 individuals completed the minimum requirement of 80% of the chosen rehabilitation protocol over the eight-week period (20-24 Grucos sessions). The three participants, whom did not complete the rehabilitation

intervention, were omitted from the data analysis. The time frame of three to nine month post-surgery was selected and implemented based on the large inter-individual variation that exists in participants following TKA surgery. The sample consisted of both men (n= 10) and women (n= 8) with a mean age of 61 years.

### 3.1.2.1 Inclusion Criteria

Prior to enrolment, participant's requirements included:

- \* Three to nine month's post-TKA.
- \* A KOOS Activities of Daily Living Subscale Score of 60-90%
- \* Completion of a Physical Activity Readiness Questionnaire (PAR-Q) to assess if they were medically fit to undergo the required testing and training. If any red flags were noted, the participants were referred to a qualified physician to assess the specific risk factor and determine if they may complete the exercise programme.
- \* A complete medical examination performed by a cardiologist or physician, including a stress ECG within the last 12 months.
- \* The willingness to complete the eight-week training protocol.
- \* Participants between 30 and 80 years old. This is the affected population group and we feel that it is critically important to perform this study within the specific demographic (age) population group commonly undergoing total knee replacements. We will be abiding by the American College of Sports Medicine (ACSM) guidelines on exercise in the elderly.
- \* A range of motion should be greater than 110° of full active flexion and less than 10° of flexion in full active extension.

- \* A Body Mass Index (BMI) less than  $40 \text{ kg.m}^{-2}$ .

### 3.1.2.2 Exclusion Criteria

Participants were rejected based on:

- \* A “yes” for any of the 10 PAR-Q questions (Appendix C), and were not cleared by a qualified physician to partake in the exercise programme.
- \* A moderate or severe effusion; assessed by balloting the knee and classified as a fluid wave (< 25cc) is graded mild, easily palpable fluid – moderate (25-60cc), and a tense knee secondary to effusion (> 60cc) is rated severe.
- \* An inadequately healed wound.
- \* Current Deep Vein Thrombosis (DVT).
- \* Bilateral TKA surgery.
- \* Symptomatic lower limb on the uninvolved side that limits activities of daily living (ADLs).
- \* Severe pain as characterised by a score of 70mm or greater on the Visual Analogue Scale (VAS) of the involved knee during ADL.
- \* Prior to data analysis, pain severity categories were defined. Participants with VAS pain scores of 30 mm or less were defined as having mild pain. Those with scores of 70 mm or more were considered to have severe pain and those from 31 mm to 69 mm moderate pain (Collins et al. 1997).
- \* Having a corticosteroid injection in either knee since the TKA surgery.
- \* Pain medication usage within the past two weeks.
- \* Any contra-indication to cardiovascular exercise as defined by the ACSM, namely:

- Recent acute myocardial infarction
  - Unstable angina
  - Ventricular tachycardia and other dangerous dysrhythmias
  - Dissecting aortic aneurysm
  - Acute congestive heart failure
  - Severe aortic stenosis
  - Active or suspected myocarditis or pericarditis
  - Thrombophlebitis or intra-cardiac thrombi
  - Recent systemic or pulmonary embolus
  - Acute infection
- \* Rheumatoid Arthritis (RA) or other rheumatologic pathology in either the involved or uninvolved limbs.

### **3.1.3 Sample Size Determination**

We calculated the effect size based on a previous study where 13 participants underwent rehabilitation post-TKA, we therefore required nine participants in each group to achieve a level of 80% power with 5% significance. A total of twenty-one participants were recruited to allow for any circumstances whereby a participant was unable to complete the rehabilitation intervention.

A randomised study design was utilised to assign participants into either the eccentric intervention or the concentric rehabilitation group. Participants were allocated a number according to the timing of their enrolment and were then allotted the corresponding envelope designating the specific exercise intervention.

## **3.2 TESTING AND REHABILITATION PROTOCOL**

The testing protocol and procedures implemented in this trial consist of the following:

### **3.2.1 Health Questionnaires and Surveys**

3.2.1.1 Knee Injury and Osteoarthritis Outcome Score (KOOS)

3.2.1.2 The SF-36 Health Survey

3.2.1.3 Tegner Activity Scale

### **3.2.2 Electromyography (EMG)**

### **3.2.3 Muscle volume calculations**

### **3.2.4 Isokinetic Strength assessment**

### **3.2.5 Motion Capture**

3.2.5.1 Sit-to-Stand Transfer

### **3.2.6 Eccentric and Concentric Intervention**

### **3.2.1 Health Questionnaires And Surveys**

The Knee Injury and Osteoarthritis Outcome Score (KOOS), the SF-36 health survey and the Tegner activity scale, will be documented prior to and following the eight-week rehabilitation intervention.

#### **3.2.1.1 Knee Injury And Osteoarthritis Outcome Score (KOOS)**

The Knee injury and Osteoarthritis Outcome Score (KOOS) (Appendix D) is a patient-reported outcome measurement instrument, developed to evaluate a patient's individual opinion about their knee and associated problems. It is in effect

an extension of the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), which is the most commonly used outcome instrument for assessment of patient-relevant treatment effects in OA. The KOOS (ICC > 0.75) is a valid, reliable and responsive outcome measure in total joint replacement and in comparison to the WOMAC, the KOOS shows improved validity and may be at least as responsive as the WOMAC (Roos & Toksvig-Larsen 2003).

The KOOS consists of five subscales, which include; pain, other symptoms, function in daily living (ADL), function in sport and recreation (Sport/Rec) and knee related quality of life (QoL). The week prior to questionnaire completion is taken into consideration when answering the questions. Standardised answer options are given in a five Likert format and each question gets a score from zero to four. A normalised score (100 indicating no symptoms and 0 indicating extreme symptoms) is calculated for each subscale. Each subscale score was calculated independently using the mean score of the individual items for the subscale and then dividing the value by the highest possible score. This score was calculated as a percentage (%).

### **3.2.1.2 The SF-36 Health Survey**

The SF-36 (Appendix E) is a valid and reliable (ICC ≥ 0.85) self-report survey related to different aspects of patient health (Marx et al. 2003). It is a multi-purpose, short-form health survey with only 36 questions. It yields an eight-scale profile of functional health and well-being scores as well as psychometrically based physical and mental health summary measures and a preference-based health utility index (Ware 1999). The survey subscales include features related to vitality, physical functioning, bodily

pain, general health perceptions, physical role functioning, emotional role functioning, social role functioning and mental health. The scoring system for the SF-36 generates individual subscale scores for physical functioning; role limitations due to physical, social and emotional aspects; bodily pain; general health; vitality and mental health (Ware & Sherbourne 1992).

### **3.2.1.3 The Tegner Activity Scale**

The Tegner Activity Scale (Appendix F) is a valid and reliable ( $ICC \geq 0.85$ ) measure of physical activity (Tegner, 1985; Marx et al. 2003). The activity scale is a numerical scale ranging from zero to ten. Each value indicates the ability to perform specific activities. An activity level of ten corresponds to participation in competitive sports, including soccer, football, and rugby at the elite level; an activity level of six points corresponds to participation in recreational sports; and an activity level of zero is assigned if a person is on sick leave or receiving a disability pension because of knee problems.

### **3.2.2 Electromyography (EMG)**

EMG was recorded during the isokinetic strength testing and sit-to-stand transfer. The test-retest reliability of EMG and peak torque during repetitive maximum concentric knee extensions for absolute root mean square (RMS) of rectus femoris ( $ICC \geq 0.80$ ), vastus medialis ( $ICC \geq 0.88$ ) and vastus lateralis ( $ICC \geq 0.82$ ) are reliable variables obtained from an isokinetic endurance test of the knee extensors (Larsson et al. 2003).

The EMG electrodes were placed on the participants prior to the sit-to-stand analysis, and were not removed until the isokinetic strength testing was complete. The skin overlying the belly of the muscle was shaved and cleaned using alcohol prior to the placement of the bipolar surface EMG electrodes (electrode type: blue sensor SP-00-S/50, Medicotest, Denmark). The electrodes were placed on the belly of the muscle in accordance with the SENIAM recommendations as previously described (Hermens et al. 2000).

The EMG signal was taken from the following muscles: vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) on both the involved and uninvolved legs. In addition, a reference marker for EMG signal control was placed on the anterior superior iliac spine (ASIS) of the hip. The measured signals were transmitted using a telemetry system (Telemetry 2400 T, G2). The data was captured at 2000 Hertz (Hz). The transmitter unit was placed in a halter strapped to the participants' back; this technique contributes to minimising the movement artefact of EMG signal. The raw digital EMG signal was processed using Noraxon's Myoresearch software and filtered using a 50 Hz notch filter to remove any electrical interference from external sources (MyoResearch 2.02). The signal was then be filtered a second time using a 15-500 Hz band pass filter. This allowed noise or movement interference below 15 Hz and other non-physiological signals above 500 Hz to be removed. The data was rectified and then smoothed using root mean squared analysis (RMS), which was calculated for a 50 ms window. The mean EMG amplitude values were calculated using the ten repetitions during the isokinetic strength testing trials and normalised to the peak amplitude of the second repetition in each trial.

### **3.2.3 Muscle Volume And Cross- Sectional Area**

The anterior mid-thigh skinfold measurement, the sub-gluteal, mid-thigh and above-knee circumferences of both legs was recorded to calculate the lean thigh volume (LTV). This technique for estimating LTV assumes the upper section of the lower limb has the shape of a truncated cone. The technique was adapted from the technique described by Katch and Katch (Katch & Katch 1974) and has been validated against LTV assessed by magnetic resonance imaging (Knapik et al. 1996).

The mid-point on the anterior surface of the thigh was identified and a skin fold was measured at this point with the fold parallel to the long axis of the thigh. Each participants weight was on the other leg allowing the knee joint at an angle of about 120°. The mid- thigh girth is measured at the level at which the skinfold was taken. The sub-gluteal girth was then measured at 1 cm below the gluteal fold. The participants weight was distributed evenly on both legs during the taking of the above-mentioned measurements. The above-knee girth was measured at 1 cm above the superior border of the patella. The sub-gluteal-above-knee length was measured as the distance between the sub-gluteal girth and the above knee girth measurements.

### **3.2.4 Isokinetic Strength Assessment**

Quadriceps and Hamstring strength was measured for both the involved and uninvolved sides using a Biodex Isokinetic Dynamometer (ICC $\geq$  0.95) (Biodex

Medical Systems Inc., Shirley, NY) (Feiring et al. 1990). The participants performed concentric contractions of the quadriceps and hamstrings muscle groups through knee extension and flexion for functional strength measurements. Dynamometer orientation was  $90^\circ$  with dynamometer tilt set at  $0^\circ$ . Participants were securely strapped into the chair with the lateral femoral condyle (in the sagittal plane) aligned with the axis of the rotation of the dynamometer, to allow for smooth movement through flexion and extension of the knee joint.

A familiarisation trial took place within one-week prior to the actual pre-testing day where the participants were familiarised with the equipment and protocol before trial testing. The seat setup and range of motion for the participant was recorded so that setup and testing was smoothly executed on the day of testing. Participants held an emergency stop button at all times during the testing procedure, so that they could immediately stop the dynamometer at any time if necessary.

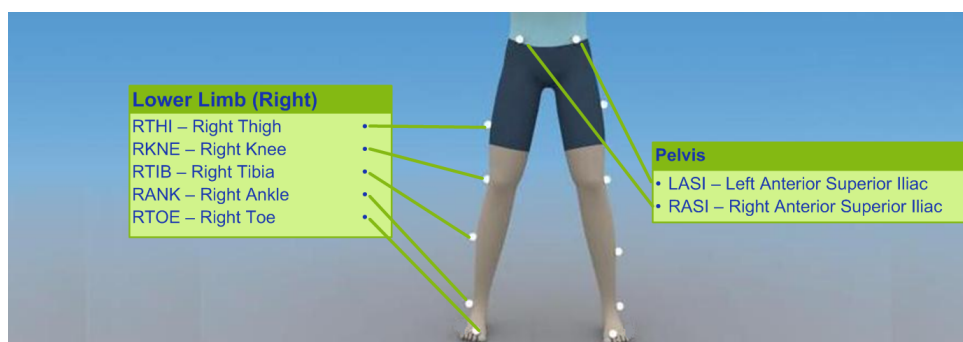
A trial warm-up set of five repetitions (reps) was performed before a maximal trial of ten reps was performed at  $120 \text{ deg/sec}$ . The investigators provided verbal encouragement as a means of motivation for the participant during the test. Similarly, the visual output of the participants force was displayed, providing feedback in order to facilitate the maximum force output. This test was normalised to the second repetition of each completed set. The reason behind excluding a maximal voluntary contraction (MVC) was to minimise any excessive load placed on the joint so early after surgery, thus reducing the risk of injury and pain or discomfort for the participant. This process was repeated for each leg. Standardisation was enhanced

by performing a gravity correction, which entails the weighing of the leg via gravity, and participants placing their arms across their chests during all testing.

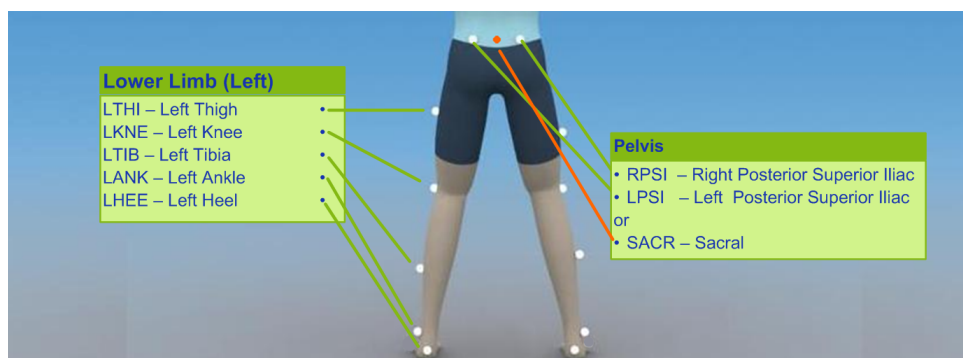
### **3.2.5 Motion Capture**

Kinematic and kinetic data was recorded using an AMTI® force plate and an eight-camera Vicon motion capture system (Oxford Metric Vicon). The Vicon motion capture system was used to analyse knee and hip joint angles while standing up from a seated position (sit-to-stand transfer). Kinetic data (ground reaction force) was recorded at 1000 Hz on two separate force plates hidden from the participant. The kinematic data was recorded at 250 Hz using the Vicon plug-in gait marker set (Vaughan & Davis 1999) which allowed for the measurement of all joint locations and angles of rotation, as well as the calculation of joint moments. Analysis of the kinematic data is focused on the range of the joint angles, as well as the joint angles and moments during specific phases during the sit-to-stand transfer.

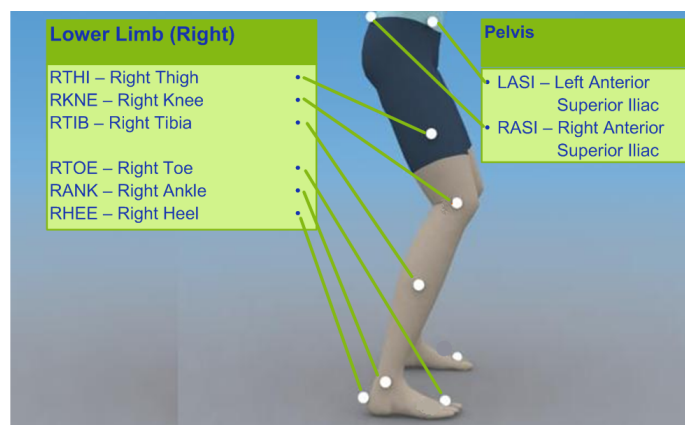
Retro reflective anatomical markers were placed bilaterally according to the Plug-in Gait lower body modelling marker sets designed for the Newington-Helen Hayes model on which Plug-in Gait is based. The marker set included markers for the pelvis and the lower limbs. A standing calibration was performed prior to the motion capture of the sit-to-stand trials in order to identify the joint centres with respect to each segments coordinate system. The following illustrations provide front, back, and side views of where the markers were attached for each participant according to the abovementioned guidelines, as well as the plug-in-gait variable definitions for each joint.



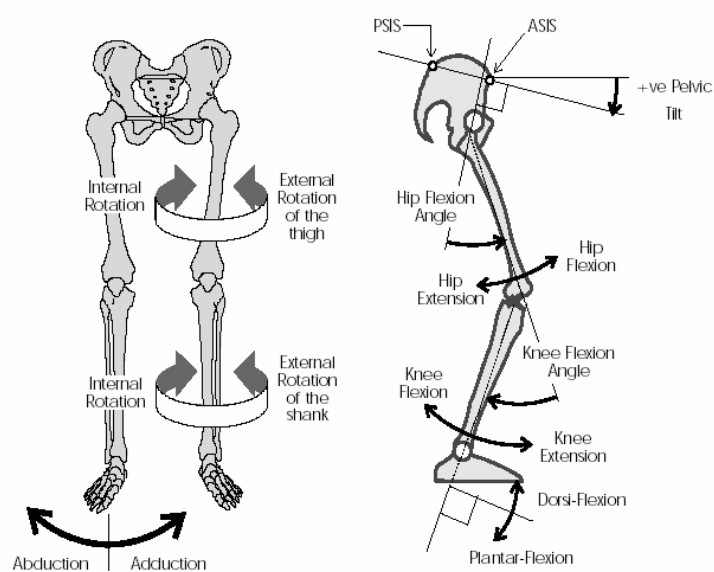
**Figure 3.1.** Image showing the front view of the marker placement for the plug-in gait for lower body models. Abbreviations: RTHI, right thigh; RKNE, right knee; RTIB, right tibia; RANK, right ankle; RTOE, right toe; LASI, left anterior superior iliac; RASI, right anterior superior iliac.



**Figure 3.2.** Image showing the back view of the marker placement for the plug-in gait for lower body models. Abbreviations: LTHI, left thigh; LKNE, left knee; LTIB, left tibia; LANK, left ankle; LHEE, left heel; RPSI, right posterior superior iliac; LPSI, left posterior superior iliac; SACR, sacral.



**Figure 3.3.** Image showing the side view of the marker placement for the plug-in gait for lower body models. Abbreviations: RTHI, right thigh; RKNE, right knee; RTIB, right tibia; RTOE, right toe; RANK, right ankle; RHEE, Right Heel; LASI, left anterior superior iliac; RASI, right anterior superior iliac.

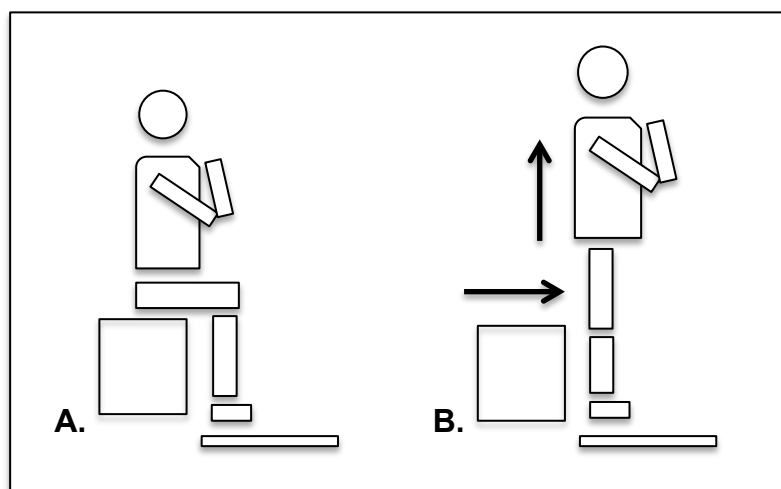


**Figure 3.4.** Image illustrating the plug-in-gait variable definitions for each joint of the lower limb. Abbreviations: PSIS, posterior superior iliac spine; ASIS, Anterior superior iliac spine; +ve, positive.

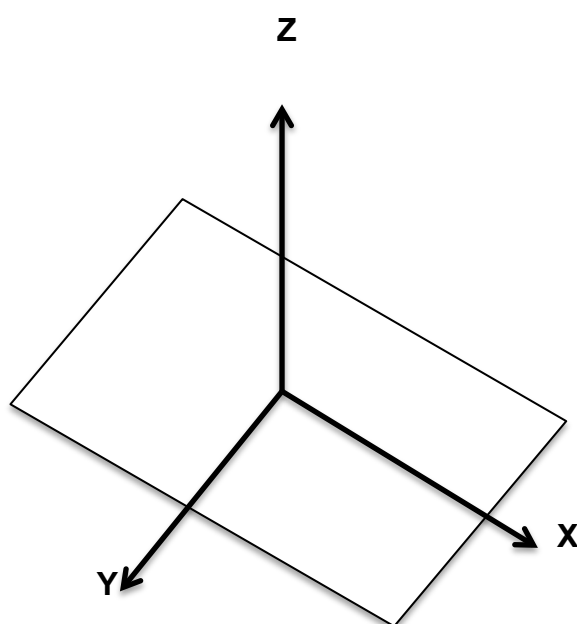
### 3.2.5.1 Sit-to-Stand Transfer

Prior to sit-to-stand (STS) trials, the participants were positioned in the centre of the calibrated area on an armless and backless chair. The height of the chair was set to the height of the each subject's knee joint line, at approximately 90° (degrees) of knee flexion. The participants were then asked to hold their arms across their chests in order to standardise the arm position across trials, as well as prevent the upper extremities from obstructing any markers during the motion capture. The participants were positioned on the chair with their feet approximately shoulder width apart, with each foot placed on a separate force plate. The participants were asked to stand up from the chair at a self-selected pace (Figure 3.5).

One practice trial was performed prior to recording in order to confirm the participants understanding of the verbal instructions. The STS data was then divided into two phases, using 45° of knee flexion as a marker. Phase one denotes the STS movement that occurs up until 45° of knee flexion, whilst phase two represents the STS movement that occurs after 45° of knee flexion. The peak values across two successful trials were used for analysis. The variables considered for analysis in this study include hip and knee joint angles, as well as the neuromuscular activity in the vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) muscles. A joint angle represents the angle between the two segments on either side of the joint and is typically measured in degrees. The hip abduction-adduction joint angle and knee valgus-varus joint angles are under investigation (Figure 3.4).



**Figure 3.5.** Image illustrating the sit-to-stand transfer. **A)** Primary seated position. **B)** Final standing position.



**Figure 3.6.** Image illustrating the forces exerted on the force plate. X: Anterior-Posterior GRF; Y: Transverse GRF; Z: Vertical GRF. Abbreviations: GRF, ground reaction force.

### **3.2.6 Eccentric And Concentric Intervention**

#### **3.2.6.1 Grucox Cycle Ergometer**

The cycle ergometer to be used in this study is known as the Grucox Rehabilitation Cycle (Figure 3.7). The Grucox isokinetic ergometer is in an upright position and is equipped with a 230 Volt, state of the art 900 Watt (W) servo-drive system (APD-VS10N, LS Mecapion, Dalseogu, Daegu City, Korea) that drives the ergometer pedals via a geared drivetrain, in either a forward or reverse direction. The servo-drive system measures the required current to maintain a selected motor speed. Torque is derived by the Servo-Drive system from the current. The servo-drive system is control by custom-developed software (Grucox CylceView), running on a Windows 7 (Microsoft, Redmond, Washington, USA) based Mecer 11.6-inch (") tablet. The speed and maximum torque allowed is set on the CycleView software. The maximum torque output serves as a safety feature, whereby, if the participant surpasses the prescribed maximum torque, the participant will be able to stop the pedals, preventing over-exertion and possible harm. In addition, while the Grucox ergometer is being used, the CycleView software captures and displays the torque and power (Figure 3.8). Due to the pedals being mechanically driven by the servo-drive system at the pre-set pedal speed (cadence), the Grucox ergometer may be used to exercise either concentrically or eccentrically. Eccentric work is created by resisting against the driven pedals, with the aim of stopping the pedals. Concentric work is created when the participant exerts a force in the same direction of the driven pedals.



**Figure 3.7.** The Grucox Cycle Ergometer utilised in the research thesis rehabilitation intervention.



**Figure 3.8.** The Grucox Cycle Ergometer 11.6" touch LCD display.

### 3.2.6.2 Rehabilitation Intervention

Participants were required to attend three, 20-minute exercise sessions per week over a period of eight weeks. Participants were randomised to either a concentrically biased or eccentrically biased training rehabilitation intervention. Participants were blinded to the fact that they were randomised to either a concentric or an eccentric intervention, and were simply instructed that they were performing an exercise intervention.

Participants randomised to the eccentrically biased intervention were encouraged to slow down the pedals of the Grucox ergometer, while the pedals are either driven in a forward or reverse direction. Participants randomised to the concentric exercise group were instructed to accelerate and push the pedals in the direction the pedals are moving, either forward or backwards. Power (Watts) and work (Joule's) was recorded during each intervention session using the Grucox Cycle Ergometer. Power produced both eccentrically and concentrically was captured separately. The eccentric intervention group were instructed to exercise only eccentrically (i.e. slow the pedals down).

Participants were instructed to attend the exercise sessions at the University of Cape Town three times a week, typically on a Monday, Wednesday and Friday to allow for a rest day in between sessions. The participants performed the 20-minute cycling session consisting of a passive two minute warm up, followed by two eight-minute period of performing either eccentric or concentric exercise, with a one-minute rest period between the two eight-minute intervals (Appendix G). A registered

biokineticist or physiotherapist was present at each intervention session to coordinate adherence to the protocol, as well as record heart rate and level of pain via a VAS scale. The VAS and HR were recorded at zero, five, nine, ten, 14, and 20 minutes (Appendix H). Participants were required to complete a minimum of 80% (n= 20) of the exercise sessions to be included in the analysis of the study.

The Borg Rating of Perceived Exertion (RPE) scale is used to describe perceived exertion and was utilised in this study as a tool to determine if the participants were exercising at the desired level of intensity of physical activity for each Grucox session. This is a subjective measurement tool and is based on an individual's perception of physical exertion. The scale is based on a number of bodily sensations a person typically experiences during physical activity. These may include factors such as increases in heart rate and respiration rate, increased sweating and muscle fatigue (Borg 1998).

The participants were instructed to assign a numeric value relative to their current level of perceived exertion, according to the Borg Scale of Perceived Exertion (Appendix I). Thereafter, the Grucox settings for both the maximum torque allowed and speed were adjusted according to this reported perception of effort. This ensured that the desired intensity of each exercise session was achieved in order to ensure progression over the eight-week period. The first exercise session of the rehabilitation intervention was used to familiarise the participants to the Grucox ergometer and was set at an "extremely light" intensity. If a patient has an absence of exacerbation of pain or effusion, he or she was allowed to gradually progress. The

exercise intensity and physical demand increases every one or two weeks where it peaks at “hard” or a “15” on the Borg Scale (Appendix J).

The Borg Rating of Perceived Exertion (RPE) scale was chosen as a means to monitor and match the exercise intensity between the ECC and CON group. One of the primary aims of this thesis was to determine if the eccentric and concentric rehabilitation protocols were feasible in patient’s three to nine months’ post-TKA. In a clinical setting, the primary indication of exercise tolerance is participant discomfort and perceived exertion levels. Thus, we determined that matching intensity through alternate measures such as force or work would not be accurate representation of exercise tolerance in such an environment. The Borg scale enabled the investigators to match perceived intensity as well as monitor the participants exercise tolerance, along with heart rate and pain, throughout each exercise session. Research indicates that eccentric muscle contractions may produce two to three times the force production of a typical isometric or concentric muscle contractions (Lindstedt et al. 2001; Roig et al. 2009). Additionally, research has shown that when eccentric and concentric cycling is matched in terms of force production; oxygen consumption, heart rate and muscle activation are significantly lower during eccentric cycling when compared with concentric cycling (Bigland-Ritchie et al. 1973; Dufour et al. 2004; Dufour et al. 2006). Thus, by matching the exercise intensity using RPE, it was also possible to investigate and compare heart rate, power and work output as well as pain outcomes during the rehabilitation intervention.

A Visual Analogue Scale (VAS) was employed in order to evaluate the participants' perception of pain pertaining to the involved knee joint during each intervention

session. This measurement tool comprises of a line on a blank page with clearly defined endpoints denoting a current state of being. The line is used as a reference guide to indicate the participants' perceived level of pain ranging from the complete absence of pain to the most pain imaginable (Appendix K). The most preferred physical state, that being a complete lack of pain, is placed at the furthest point of the left hand side of the line, whilst the least desirable state i.e. an unbearable degree of pain, is placed at the other end, or right hand side of the line (McDowell 2006; Rissanen et al. 1996).

The VAS reference line measures 100 mm long, whereby each millimetre represents a percentage of overall knee pain. The journal article conducted by Jones et al., suggests that pain responses may be clustered into three ranges: one to four for mild pain, five to six for moderate pain, and seven to ten for severe pain, however these may differ when using different populations, types of pain, and pain-reference points (Jones et al. 2007). This scale was employed to evaluate each participant's degree of discomfort prior to and during each exercise session, as well as serving as means to identify and reduce potential risk for further joint damage. Each participant was asked to make a mark on the line indicating their current degree of pain within their operated knee.

The participant's heart rate (HR) was captured at set intervals using a Suunto T6 heart rate monitor (Vantaa, Finland), during each rehabilitation session (Appendix L). The maximum heart rate for each rehabilitation session, as well as the average of the three weekly sessions,, was recorded. The overall heart rate was calculated by averaging each session's maximal heart rate across all eight weeks.

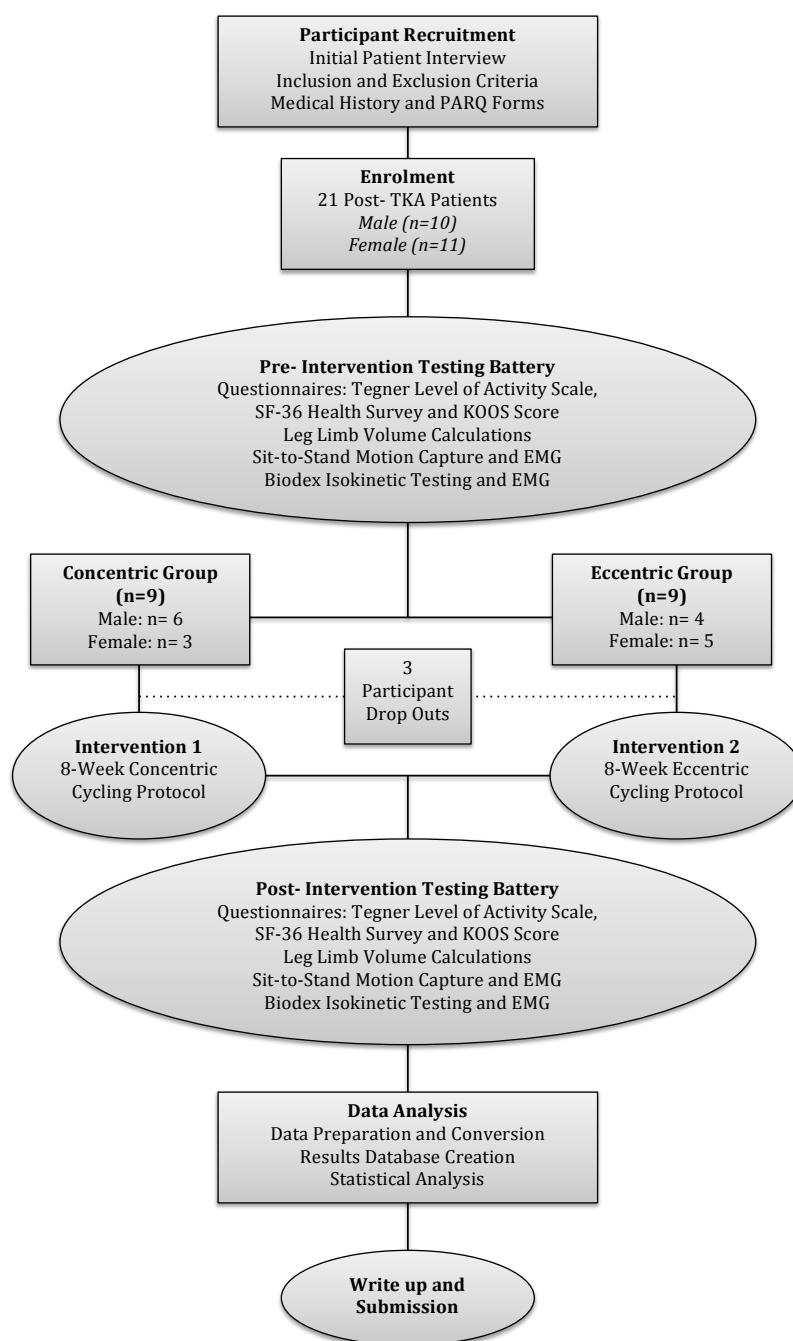
### 3.3 STATISTICAL ANALYSIS

The sample size was based on previously published results of improvements in quadriceps strength and volume resulting from a six-week eccentric resistance training programme as the primary outcome measure (Marcus et al. 2011). Based on the effect size shown in the previous study of patients undergoing rehabilitation post-TKA, it was calculated that nine patients in each group was required to achieve a level of 80% power and with 5% significance. Data were analysed using STATISTICA Software System, Version 12.0 (Statsoft Inc., Tulsa, Oklahoma, USA. [www.statsoft.com](http://www.statsoft.com)). Levene's test for equal variance and assumptions for parametric statistical tests were performed. Two-way repeated-measures analysis of variance with factors of group and time were used to analyse the effects of time and the ECC and CON intervention groups and the group/time interaction for each of the dependent variables. The Tukey post hoc examination of mean values was performed when required. Paired t-tests were used to test for differences between the pre-rehabilitation values and the post-rehabilitation values for all dependent variables.

Effect size calculations were performed in order to characterise the clinical significance as opposed to the statistically significant differences in the study outcomes of the rehabilitation intervention and between groups (Hopkins 2002). The between group differences were calculated by subtracting the difference of the means of the eccentric group from the difference of the means of the concentric group and dividing this value by the concentric groups pre-test standard deviation. The effect size for within group differences was calculated using the difference

between the means divided by the mean standard deviation. The criteria used in the classification of effect sizes are as follows:  $< 0.1$ = trivial,  $0.1- 0.3$ = trivial to small,  $0.3- 0.5$ = small,  $0.5- 0.7$ = small to moderate,  $0.7- 1.1$ = moderate,  $1.1- 1.3$ = moderate to large,  $1.3- 1.9$ = large,  $1.9- 2.1$ = large to very large,  $> 2.1$ = very large; which were adapted from the Hopkins criteria in Sportscience 6 (Hopkins 2002). All data sets were tested for outliers using the Median Absolute Deviation (MAD) method described by Leys et al. (Leys et al. 2013). Data points identified as invalid were excluded from the statistical analysis. Statistical significance for all tests was accepted when  $P < 0.05$ .

## 3.4 SUMMARY OF STUDY PROCESS



**Figure 3.9.** Summary of the steps followed in the research process. Abbreviations: PARQ, Participant Activity Readiness Questionnaire; TKA, total knee arthroplasty; n, number of participants; KOOS, Knee Injury and Osteoarthritis Outcome Score.

**CHAPTER 4****STUDY 1: THE FEASIBILITY OF AN ECCENTRIC VERSUS CONCENTRIC  
CYCLING ERGOMETRY REHABILITATION INTERVENTION IN PATIENTS POST  
TOTAL KNEE ARTHROPLASTY****4.1 INTRODUCTION**

Total knee arthroplasty (TKA) surgery, while on the most part highly effective in reducing pain associated with OA, may leave participants dissatisfied with their overall level of physical functioning following surgery (Sloan et al. 2009). A principal post-operative feature is that of distinctive muscle weakness (Berth et al. 2002; Silva et al. 2003; Walsh et al. 1998; Yoshida et al. 2008), highlighting the need for efficient rehabilitation. As a result of this limited post-operative capability, it is important to identify the most efficient means of restoring physical function with minimal adverse side effects, such as pain and additional harm.

Despite the large amount of research highlighting the advantages of eccentric rehabilitation, as shown in section 1.4.2.4, the typical standardised rehabilitation protocol following a TKA consists of home based concentric exercises, most of which have reported less than favourable results. Additionally, although eccentric training seems an effective means of restoring knee function, no study, to our knowledge has compared eccentric to concentric training rehabilitation intervention, which are matched in duration and perceived exertion. Consequently, the need for further research has become evident

A recent case series conducted by Marcus et al. (2011) investigated the effects of a six-week eccentrically biased rehabilitation intervention in participant's four weeks post-TKA. The six-week rehabilitation intervention was performed on a recumbent eccentric stepper and resulted in improvements in physical and muscle function endpoints to norm-based levels. Although, it is commonly reported that eccentric contractions are associated with muscle damage and pain and may result in injury (Whitehead et al. 1998; Proske & Morgan 2001), the eccentric intervention programme used by Marcus et al. (2001) did not result in greater than mild perceived muscle and knee pain.

The objectives of this study (study 1) was to describe pain, heart rate, and workload when the rehabilitation intervention described in section 3.2.6.1, was performed either eccentrically or concentrically, matched duration and perceived exertion, in participants as early as three months post-TKA. Additionally, the aim is to determine if an eccentric cycling ergometry rehabilitation intervention is feasible with regards to levels of pain or discomfort when compared to a concentric cycling ergometry rehabilitation, matched in duration and perceived exertion, in order to determine which exercise modality is most effective in restoring knee function in participants as early as three months post-TKA.

## **4.2 METHODOLOGY**

### **4.2.1 Participants**

A total of 18 male and female participant's three to nine months' post-TKA surgery, were recruited and randomised to perform either the eccentric (ECC group; eccentrically-biased) or concentric (CON group; concentrically-biased) intervention programme. Each group consisted of nine participants. Inclusion and exclusion criteria are listed in section 3.1.1.

### **4.2.2 Rehabilitation intervention**

The rehabilitation intervention is described in section 3.2.6.2. Both the CON group and the ECC group were prescribed to perform the three, 20-minute exercise sessions per week, for eight weeks at the same level of exertion, as described in section 3.2.6.2.

Participants reported to the Grucox Laboratory at the Sports Science Institute of South Africa in Newlands, Cape Town for each intervention session on Mondays, Wednesdays and Fridays, allowing at least one days rest between sessions. A registered biokineticist or physiotherapist was present to coordinate adherence to the protocol, as well as record heart rate and level of pain via a VAS scale, as described in section 3.2.6.2 (Figure 4.2).

In this particular study, the exercise intensity was gradually progressed during the eight-week period. Prior to and during the sessions, participants were asked and reminded to match their perceived exertion according to the Borg rating of perceived exertion (RPE) scale as described in section 3.2.6.2 (Borg 1998). The pedal speed (cadence) during each session was modified according to the participant's reported perception of effort. This ensured that the desired intensity of each intervention session was achieved in order to ensure progression over the eight-week period. In order to assess if participants were compliant to the instruction, they were asked to report their RPE at set intervals as described in section 3.2.6.2.

The maximum RPE reported by the participant in each session was recorded and the average of these maximums for the three weekly sessions were calculated per participant. Comparative analyses were then conducted to identify variances between the intervention groups.

#### **4.2.3 Pain Visual Analogue Scale**

A Visual Analogue Scale (VAS), described in section 3.2.6.2, was employed in order to record the pain the participant experienced during the rehabilitation intervention within the involved knee during each intervention session (McDowell 2006; Rissanen et al. 1996). The VAS reference line measures 100 mm, where each millimetre represents a percentage of overall knee pain. Pain responses were clustered into three ranges: 0 to 40 mm for mild pain, 41 to 69 mm for moderate pain, and 69 to 100 mm or severe pain, as previously described (Jones et al. 2007). The maximum

level of pain expressed in each session was recorded and an average from the three weekly sessions was calculated per participant.

#### **4.2.4 Heart Rate**

The participant's heart rate (HR) was captured using a Suunto T6 heart rate monitor (Vantaa, Finland), during two-minute intervals, during each rehabilitation session (Appendix L). The maximum heart rate for each rehabilitation session, as well as the average of the three weekly sessions was recorded. The overall heart rate was calculated by averaging each session's maximal heart rate across all eight weeks.

#### **4.2.5 Workload**

The power (Watts) and work (Kilojoule's) produced by the participants during each intervention session was recorded by the Grucox Cycle Ergometer, as described in section 3.2.6.2, Power produced both eccentrically and concentrically was captured separately. Although the eccentric intervention group was instructed to exercise eccentrically (i.e. slow the pedals down), the participants may still have produced concentric power. The opposite would be true for the concentric intervention group. Therefore, the mode specific power output refers to the given intervention group's power output in the desired mode of exercise (eccentric power output of the eccentric group) and the non-mode specific power refers to the power produced in the undesired mode of exercise (eccentric power output of the concentric group). The average mode specific and non-mode specific power output across the 18-minute period of each intervention session was recorded. The non-mode specific

power produced will be accounted for in the work performed and therefore was not included in the data analysis. The weekly power outputs represent the weekly average power for all three sessions.

Work was calculated from total power (both mode specific and non- mode specific power) as shown in Figure 4.1.A. Power was calculated as shown in Figure 4.1.B. The total work represents the sum of the work produced during each data recording.

$$\mathbf{A) \Delta Work = (Mode\ Specific\ Power * \Delta\ Time) + (Non- Mode\ Specific\ Power * \Delta\ Time)}$$

And

$$\mathbf{B) Power = Torque * Speed * (2\pi/60)}$$

**Figure 4.1.** The formula's used to calculate work (A) and power (B). Where “ $\Delta$ ” refers to an incremental or progressive change in x; work, measured in kilojoules (KJ); time, measured in seconds (s); power, measured Watts (W); torque, measured in Newton metres (N.m); speed, measured in repetitions per minute (RPM); “ $\pi$ ” or “Pi” denotes the mathematical constant 3.142.

Minute	Instruction	
1	Passive ROM in Reverse Direction	← VAS, HR & RPE
2		← VAS, HR & RPE
3	Active ROM in Reverse Direction	← VAS, HR & RPE
4		
5		
6		← VAS, HR & RPE
7		
8		
9		
10		← VAS, HR & RPE
11	Passive ROM in Forward Direction	← VAS, HR & RPE
12	Active ROM in Forward Direction	← VAS, HR & RPE
13		
14		
15		← VAS, HR & RPE
16		
17		
18		
19		← VAS, HR & RPE
20	Passive ROM in Forward Direction	← VAS, HR & RPE
		← VAS, HR & RPE

**Figure 4.2.** A brief outline of the steps taken during each intervention session. Abbreviations: ROM, range of motion; VAS, visual analogue scale; RPE, rate of perceived exertion.

#### **4.2.6 Statistical Analysis**

Data were analysed as described in section 3.3.

## 4.3 RESULTS

### 4.3.1 Descriptive Characteristics

At the time of recruitment, age ( $P=0.466$ ), weight ( $P=0.908$ ), height ( $P=0.604$ ), and BMI ( $P=0.526$ ) were matched between the participants randomised into the ECC and CON intervention groups (Table 4.1).

The ECC and CON groups were also matched for sex ( $P=0.637$ ) and number of days between surgery and recruitment into the study ( $P=0.219$ ). Further, weight ( $P=0.904$ ) and BMI ( $P= 0.501$ ) remained matched after the eight-week intervention period.

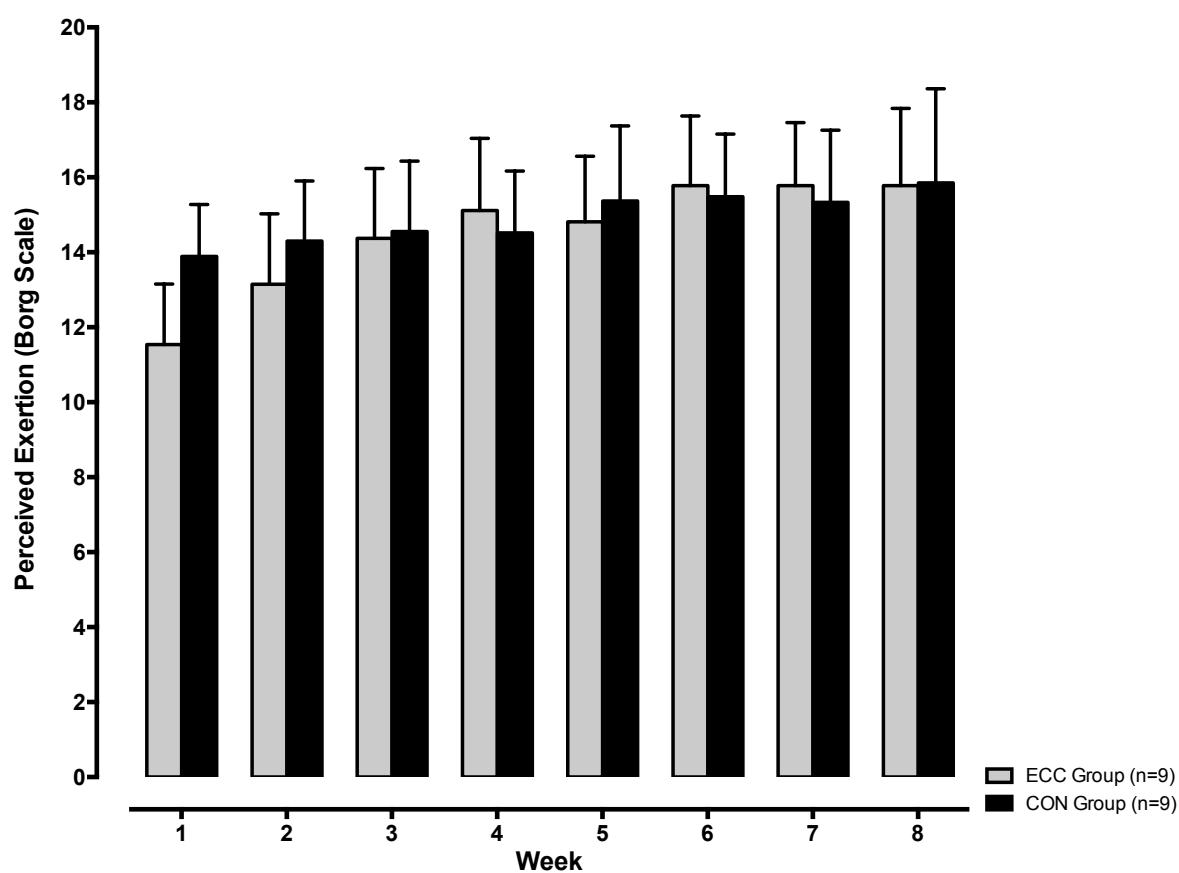
**Table 4.1. A comparison of the descriptive characteristics between the eccentric (ECC group) and concentric (CON group) intervention group.**

Variable:	INTERVENTION GROUP		P <sup>1</sup>
	ECC Group (n=9)	CON Group (n=9)	
Age (Years)	58.4 ± 13.1	63.4 ± 15.3	0.466
Sex (% Male)	44.4	66.7	0.637
Post-operative Time (Days)	156.3 ± 42.1	133.2 ± 34.1	0.219
Height (m)	1.7 ± 0.1	1.7 ± 0.1	0.604
Pre Weight (kg)	87.8 ± 16.1	86.8 ± 17.8	0.908
Post Weight (kg)	88.8 ± 16.9	87.8 ± 17.1	0.904
Pre BMI (kg.m <sup>-2</sup> )	30.1 ± 5.1	28.7 ± 4.2	0.526
Post BMI (kg.m <sup>-2</sup> )	30.4 ± 5	28.9 ± 3.8	0.501

<sup>1</sup>: ECC vs. CON. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; P, P-value; Pre, pre-intervention testing battery; Post, post-intervention testing battery; BMI, body mass index; %, percentage; m, metres; kg, kilograms.

### 4.3.2 Intervention Adherence

The average Borg rating of perceived exertion (RPE) recorded across the rehabilitation intervention was not significantly different ( $P=0.627$ ) between the ECC and CON intervention groups (Figure 4.3).



**Figure 4.3.** A comparison of the weekly RPE values for the ECC and CON intervention groups. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants.

### **4.3.3 Pain Visual Analogue Scale**

The level of pain reported during each exercise session across the rehabilitation intervention was not significantly different ( $P=1.000$ ) between the ECC and CON intervention groups (Table 4.2).

**Table 4.2. A comparison of the number of participants per week in each pain category between the eccentric (ECC) and concentric (CON) intervention group.**

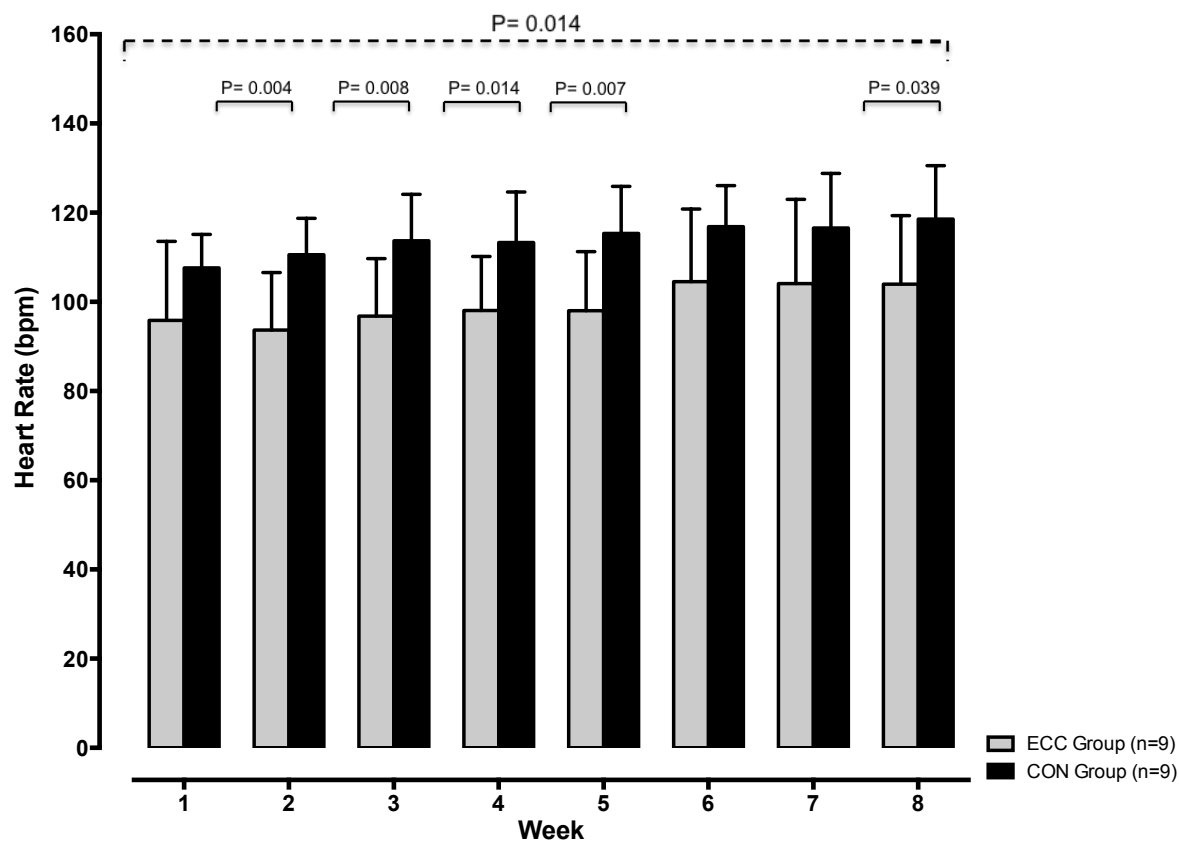
Variable:	INTERVENTION GROUP									
	ECC Group (n=9)					CON Group (n=9)				
	None (0-0.9)	Mild (1-4)	Moderate (5-6)	Severe (7-10)	Severe (7-10)	None (0-0.9)	Mild (1-4)	Moderate (5-6)	Severe (7-10)	Severe (7-10)
Week 1	8	1	0	0	0	8	1	0	0	0
Week 2	8	1	0	0	0	8	1	0	0	0
Week 3	8	1	0	0	0	8	1	0	0	0
Week 4	8	1	0	0	0	8	1	0	0	0
Week 5	7	2	0	0	0	8	1	0	0	0
Week 6	8	1	0	0	0	8	1	0	0	0
Week 7	8	1	0	0	0	8	1	0	0	0
Week 8	9	0	0	0	0	8	1	0	0	0

*Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants.*

#### **4.3.4 Heart Rate**

The HR recorded across the rehabilitation intervention was significantly higher ( $P=0.014$ ) in the CON group in comparison to the ECC intervention group (Figure 4.2).

The HR recorded at week 2 (ECC  $93.7 \pm 12.9$  bpm; CON  $110.6 \pm 8.1$  bpm;  $P=0.004$ ), week 3 (ECC  $98.8 \pm 12.9$  bpm; CON  $113.7 \pm 10.5$  bpm;  $P=0.008$ ), week 4 (ECC  $98.1 \pm 12.1$  bpm; CON  $113.3 \pm 11.3$  bpm;  $P=0.014$ ), week 5 (ECC  $98 \pm 13.2$  bpm; CON  $115.3 \pm 10.6$  bpm;  $P=0.007$ ) and week 8 (ECC  $103.9 \pm 15.4$  bpm; CON  $118.6 \pm 11.9$  bpm;  $P=0.039$ ) was significantly higher in the CON group in comparison to the ECC intervention group (Figure 4.4). There were no further significant differences.



**Figure 4.4.** A comparison of the weekly heart rate values for both the ECC and CON intervention groups. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; bpm, beats per minute.

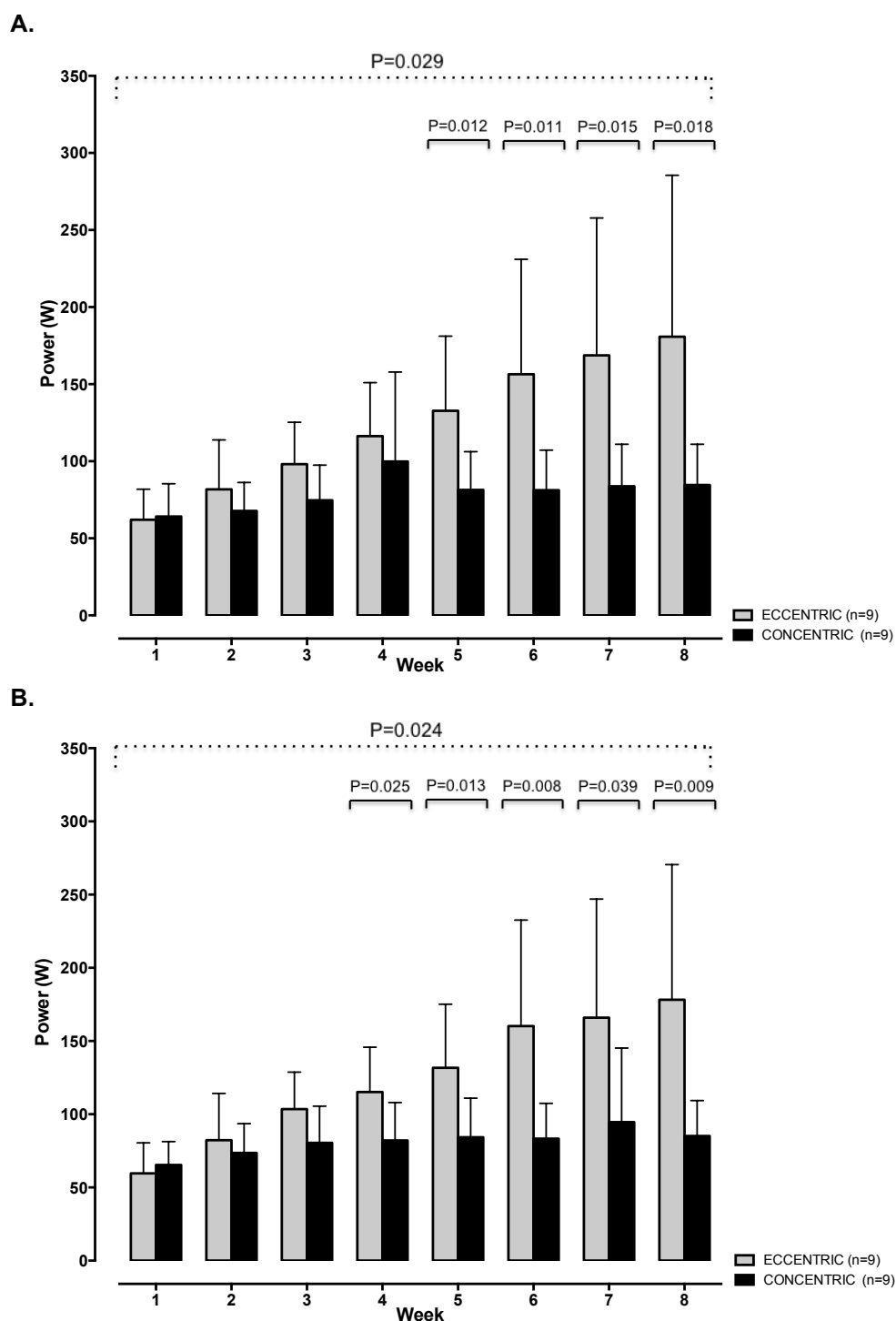
### **4.3.5 Workload**

#### **4.3.5.1 Mode Specific Power Output**

The mode specific power produced across the rehabilitation intervention by the involved limb ( $P=0.029$ ) and the uninvolved limb ( $P= 0.024$ ) was significantly higher in the ECC group in comparison to the CON intervention group.

The mode specific power produced by the involved limb in week 5 (ECC  $132.8 \pm 48.4$  W; CON  $81.4 \pm 24.8$  W;  $P= 0.012$ ), week 6 (ECC  $156.5 \pm 74.6$  W; CON  $81.3 \pm 25.9$  W;  $P= 0.011$ ), week 7 (ECC  $168.8 \pm 89$  W; CON  $83.8 \pm 27.4$  W;  $P= 0.015$ ) and week 8 (ECC  $180.8 \pm 104.7$  W; CON  $84.6 \pm 26.5$  W;  $P= 0.018$ ) was significantly higher in the ECC group in comparison to the CON intervention group (Figure 4.5.A).

The mode specific power produced by the uninvolved limb in week 4 (ECC  $115.2 \pm 30.6$  W; CON  $82.1 \pm 25.9$  W;  $P= 0.025$ ), week 5 (ECC  $131.7 \pm 2.7$  W; CON  $84.3 \pm 26.6$  W;  $P= 0.013$ ), week 6 (ECC  $160.3 \pm 72.4$  W; CON  $83.3 \pm 24.1$  W;  $P= 0.008$ ), week 7 (ECC  $165.9 \pm 81$  W; CON  $94.6 \pm 50.6$  W;  $P= 0.039$ ) and week 8 (ECC  $178.2 \pm 92.2$  W; CON  $85.2 \pm 24.2$  W;  $P= 0.009$ ) was significantly higher in the ECC group in comparison to the CON intervention group (Figure 4.5.B).

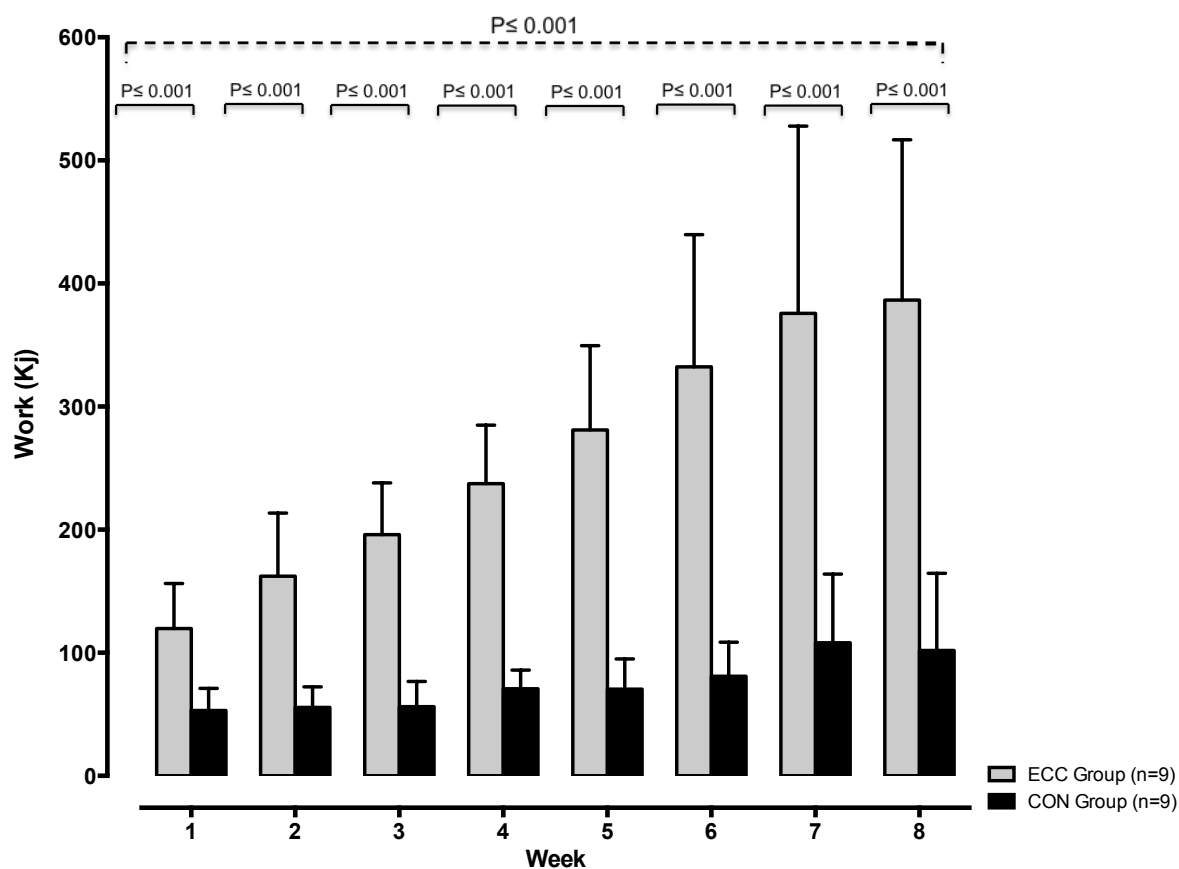


**Figure 4.5. A)** A comparison of the average weekly mode specific power output in the involved limb in the ECC and CON intervention groups, respectively. **B)** A comparison of the average weekly mode specific power output in the uninvolved limb in the ECC and CON intervention groups, respectively. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; W, Watts

#### 4.3.5.2 Work

The average work performed across the rehabilitation intervention was significantly higher ( $P \leq 0.001$ ) in the ECC group in comparison to the CON intervention group.

The work performed in week 1 (ECC  $119.7 \pm 36.5$  kJ; CON  $53 \pm 18$  kJ;  $P \leq 0.001$ ), week 2 (ECC  $162.2 \pm 51.4$  kJ; CON  $55.5 \pm 16.8$  kJ;  $P \leq 0.001$ ), week 3 (ECC  $195.9 \pm 42.1$  kJ; CON  $56.2 \pm 20.5$  kJ;  $P \leq 0.001$ ), week 4 (ECC  $237.4 \pm 47.5$  kJ; CON  $70.8 \pm 15.1$  kJ;  $P \leq 0.001$ ), week 5 (ECC  $281 \pm 68.5$  kJ; CON  $70.4 \pm 24.6$  kJ;  $P \leq 0.001$ ), week 6 (ECC  $332.3 \pm 107.4$  kJ; CON  $80.9 \pm 27.6$  kJ;  $P \leq 0.001$ ), week 7 (ECC  $375.7 \pm 152.2$  kJ; CON  $108.2 \pm 55.8$  kJ;  $P \leq 0.001$ ) and week 8 (ECC  $386.6 \pm 130.2$  kJ; CON  $101.8 \pm 62.8$  kJ;  $P \leq 0.001$ ) was significantly higher in the ECC group in comparison to the CON intervention group (Figure 4.6).



**Figure 4.6.** A comparison of the weekly amount of work produced for the ECC and CON intervention groups. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; kJ, kilojoules.

#### 4.4 DISCUSSION

This chapter describes the outputs of the Grucox Cycle Ergometry rehabilitation intervention implemented over an eight-week period. This study demonstrated that the proposed eccentric rehabilitation intervention is feasible in participants as early as three months post-TKA. The intensity, as measured by the participants perceived exertion (RPE) was successfully matched between the concentric and eccentric groups. No difference in pain was observed between the eccentric and concentric interventions. Interestingly, the eccentric group produced greater power outputs and work, with a reduced heart rate.

The ECC group achieves a significantly greater overall power and work output at the culmination of the rehabilitation intervention, approximately two times that of the next highest concentric power output. These findings support the existing theories that suggest eccentric muscle contractions may produce two to three times the force production of a typical isometric or concentric muscle contractions (Lindstedt et al. 2001).

The results for heart rate reveal that the ECC group achieves a significantly lower heart rate over the intervention period in comparison to the CON intervention group (Figure 4.2). Furthermore, the ECC group has a significantly lower heart rate at week two, three, four, five and eight. These findings mimic those of previous research studies that suggest eccentric muscle contractions require less metabolic cost or a reduced oxygen requirement when compared to a concentric muscle contraction (Abbott et al. 1952; Bigland-Ritchie & Woods 1976). Correspondingly, eccentric

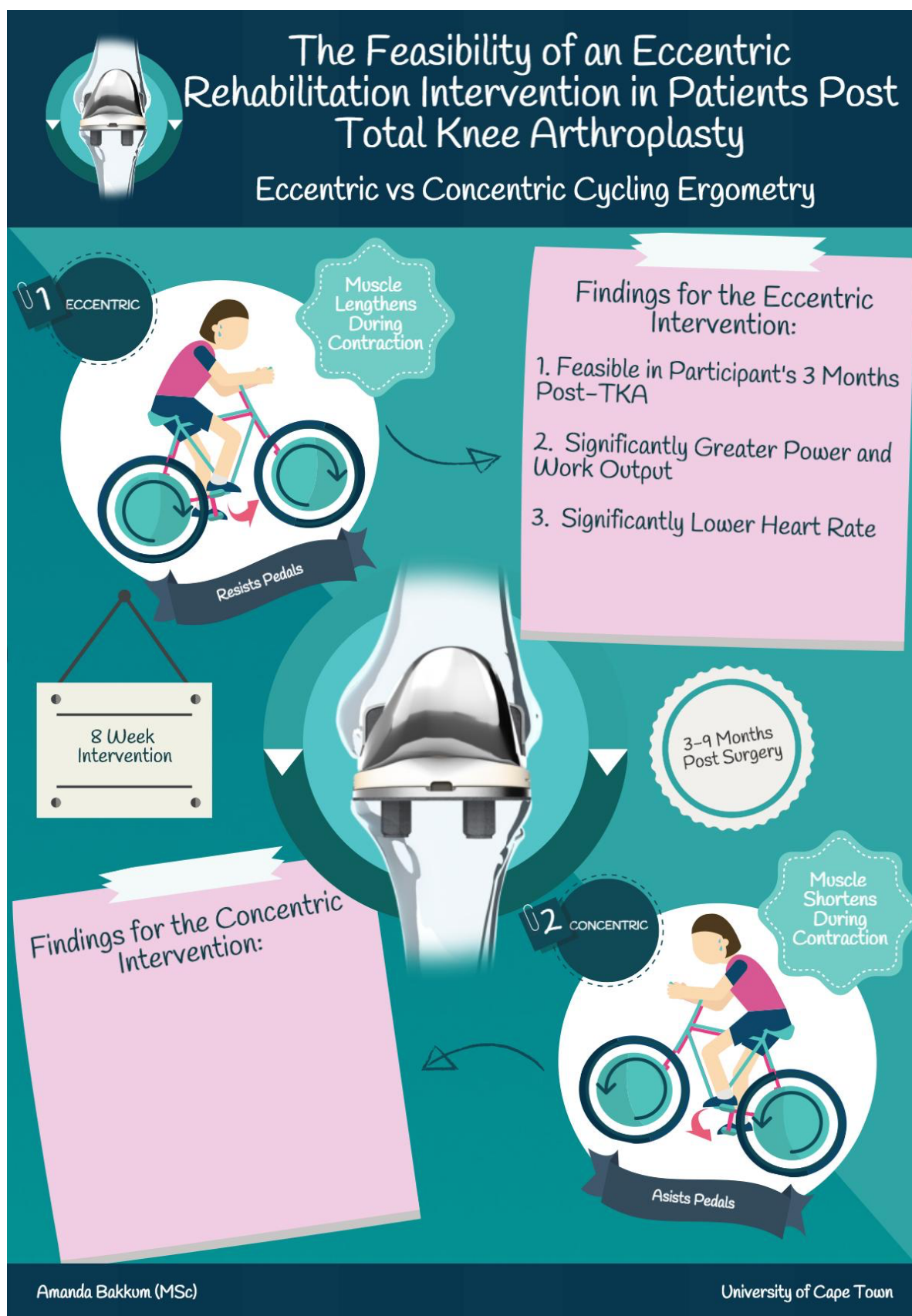
muscle activity has been shown to be largely fatigue resistant (Kay et al. 2000). From these results, it may be inferred that an eccentric work could be produced at a lower HR when compared to typical concentric or isometric efforts. These results suggest that eccentric type exercise may serve as a feasible therapeutic modality in cases where functional activity is limited, as in a TKA, as well as conditions where cardiovascular capacity is limited.

During the rehabilitation intervention, the peak level of pain perceived per session, never exceeded beyond a “mild” classification in both groups (Table 4.2). These results were mirrored in the study conducted by Marcus et al. (2011) whereby the mean perceived muscle and knee pain never surpassed a level of three over the first half of the rehabilitation sessions and diminished to approximately a level of one to two over the second half of the rehabilitation sessions (Marcus et al. 2011). These pain levels fall within the “mild” pain category described in section 4.2.4. This finding indicates that despite an increase in the duration of the rehabilitation intervention, from six to eight weeks, both the ECC and CON groups are able to tolerate the workload with regards to their perceived level of pain.

There was no statistically significance difference between the two intervention groups across the entire eight-week period in terms of the perceived level of pain. These results indicate that the intervention groups did not express a significantly different perception of pain over the eight-week rehabilitation intervention. The research suggests that eccentric muscle contractions, characterised by higher tensile forces on both muscle fibres and connective tissue, elicit greater muscle fibre damage and consequently delayed onset on muscle soreness (DOMS), when

compared to concentric muscle contractions (Whitehead et al. 1998; Proske & Morgan 2001). These results indicate that muscle soreness as a result of eccentric muscle contractions should not be a major concern when following a progressive eccentric rehabilitation intervention.

In conclusion, as both the rehabilitation interventions were well tolerated with respect to the level of perceived pain and physical exertion, it is inferred that both the concentric and eccentric rehabilitation interventions are feasible therapeutic modalities within the given population (Figure 4.7). However, due to the significantly greater power output produced and work performed at significantly lower heart rates, it may be proposed that the eccentric rehabilitation may also elicit superior gains in functional performance. This is noteworthy as, in cases where physical and cardiovascular capacity is limited, it is vital to identify means of improving functional performance whilst minimising the stress placed on the cardiovascular system. The objectives of the following chapters in this thesis are to establish the efficacy of this exercise intervention.



**Figure 4.7.** An infographic summarising the conclusions of Study 1. Abbreviations: TKA; total knee arthroplasty.

**CHAPTER 5****STUDY 2: THE EFFECTS OF AN ECCENTRIC VERSUS CONCENTRIC CYCLING  
ERGOMETRY REHABILITATION INTERVENTION ON MUSCLE STRENGTH,  
VOLUME AND ACTIVITY IN PATIENTS POST TOTAL KNEE ARTHROPLASTY****5.1 INTRODUCTION**

The predominant impairment to knee function following a TKA is a distinctive reduction in quadriceps strength that has been associated with a limitation of post-operative physical activity (Berth et al. 2002; Silva et al. 2003; Walsh et al. 1998; Yoshida et al. 2008). The loss of post-operative strength in the quadriceps may also be related to a decrease in muscle mass prior to surgery. The typical quadriceps cross sectional area of older participants awaiting TKA surgery is approximately two-thirds that of age-matched individuals (Ferri et al. 2003; Frontera et al. 2000; Gür 2002; Gür & Cakin 2003).

The subsequent muscle strength deficiencies are not well accounted for, however, it is suggested, as discussed in section 1.4, that improving quadriceps strength may mitigate these impairments and contribute to improved functional outcomes. Therefore, the role of physical rehabilitation is of particular interest, as well as how this may serve to offset the substantial muscular strength deficits that are present following surgery.

Research suggests that eccentric muscle contractions may result in greater strength improvements and may produce two to three times the force of a typical isometric or concentric muscle contraction (Lindstedt et al. 2001). In addition to this proposed enhanced force production, eccentric muscle contractions require less metabolic cost or a reduced oxygen requirement when compared to a concentric muscle contraction (Abbott et al. 1952; Bigland-Ritchie & Woods 1976). Therefore, because the eccentric contraction can produce a greater force with a lower perception of exertion levels, it may serve as an ideal therapeutic modality in cases where functional activity is limited. However, despite the wealth of research highlighting the advantages of eccentric rehabilitation, the typical standardised rehabilitation protocol following a TKA consists of home based concentric exercises, most of which have reported less than favourable results (Marcus et al. 2011). Subsequently, the need for additional research has become apparent.

A recent case series conducted by Marcus et al. (2011) investigated the effects of a six-week eccentrically biased rehabilitation intervention in participants after TKA. The six-week rehabilitation intervention was performed on recumbent eccentric stepper and resulted in improvements in the primary physical function endpoints, such as the SF-36 physical component summary and the six minute walk test, as well as improvements in muscle function endpoints, such as knee extension strength and power.

Conversely, a meta analysis conducted by Roig et al. (2009) showed that subgroup analyses in which intensity was equated as a percentage of one repetition of maximal effort (1RM) during concentric training showed no major differences between eccentric and concentric training in promoting gains in strength. In contrast, strength gains were maximised in all studies in which eccentric training was performed at higher intensities (Roig et al. 2009). Thus, although eccentric training seems an effective means of restoring knee function, no study, to our knowledge has compared eccentric to concentric training or rehabilitation interventions, which are matched in duration and perceived exertion in participants as early as three months post-TKA.

The purposes of study 2 is to investigate the effects of an eccentric rehabilitation intervention on strength related parameters and compare these effects to those of a concentric rehabilitation intervention, matched in both duration and perceived exertion. The specific aims of this study were to investigate whether an eccentric rehabilitation intervention produced greater increases in quadriceps and hamstring muscular strength, as measured using the Biodex Isokinetic Dynamometer, when compared to the concentric rehabilitation intervention. Secondly, an additional aim of this study was to investigate if the electromyography (EMG) of the vastis medialis, vastis lateralis and biceps femoris muscle activities during the isokinetic testing was different between the eccentric and concentric rehabilitation interventions. Finally, this study also aimed to determine if the eccentric rehabilitation intervention produced greater increases in lower limb muscle volume compared to the concentric rehabilitation intervention, matched in both duration and perceived exertion

## **5.2 METHODOLOGY**

As outlined in chapter 3, section 3.2.2 to 3.2.4, isokinetic strength assessments, neuromuscular activity and lean thigh volume calculation analyses were conducted prior to and following the rehabilitation intervention.

### **5.2.1 Isokinetic Strength Assessment**

Quadriceps and hamstring strength was measured for both the involved and uninvolved lower limbs as described in section 3.2.4, using a Biodex Isokinetic Dynamometer (Biodex Medical Systems Inc., Shirley, NY). The variables derived from the Biodex Isokinetic Dynamometer are described as follows.

#### **5.2.1.1 Peak Torque Per Body Weight**

Peak torque indicates the muscle's peak strength capability and was denoted as the peak torque produced throughout the isokinetic trial. This is considered to be the gold-standard measure in isokinetic testing (Kannus 1994). Peak torque during knee extension and flexion is normalised to body weight and was represented as a percentage. This was expressed as Newton Meters per kilogram (N.m/kg).

#### **5.2.1.2 Time To Peak Torque**

Time to peak torque (TtPTQ) denotes the time from the start of a muscular contraction to the peak torque in each contraction cycle during the isokinetic testing

protocol. An average was derived from the time to peak during knee flexion and extension. This measure is indicative of the muscles functional capacity to produce torque rapidly and was expressed in milliseconds (ms).

#### **5.2.1.3 Torque At 30 Degrees**

This value represents the torque produced at a pre-set angle of 30 degrees ( $^{\circ}$ ) of knee flexion. The torque at  $30^{\circ}$  (TQ $30^{\circ}$ ) was recorded during knee extension and flexion and an average is derived across each contraction cycle during the isokinetic testing protocol. The position of  $30^{\circ}$  was of particular importance during knee stabilisation and was expressed in Newton meters (N.m).

#### **5.2.1.4 Total Work**

Work was calculated by multiplying the force produced and distance covered during each contraction cycle for knee flexion and extension during the isokinetic testing, from which average values were derived. Total Work denotes the muscle's proficiency to maintain torque throughout the complete test trial and was expressed in joules (J).

#### **5.2.1.5 Work Fatigue**

Work fatigue represents the ratio of the difference between the work produced in the first third and the work produced in the last third of the test trial. This may serve as an indication of endurance to detect the level of fatigue in the test trial and was

expressed as a percentage (%). Work fatigue was recorded during knee extension and flexion.

### **5.2.2 Electromyography**

EMG was recorded during the isokinetic strength testing as described in detail in section 3.2.2. The EMG signal was taken from the following muscles: vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) on both the involved and uninvolved legs. The mean EMG amplitude values were calculated using the ten repetitions during the isokinetic strength testing trials and normalised to the peak amplitude of the second repetition in each trial.

#### **5.2.2.1 Vastus Medialis Muscle (VM)**

The VM is one the muscles that reside in the anterior compartment of the thigh. This muscle is located on the medial border of the thigh and plays an active role in knee extension. The VM forms part of the quadriceps muscle group (Drake et al. 2009).

#### **5.2.2.2 Vastus Lateralis Muscle (VL)**

The VL muscle is located on the lateral border of the anterior compartment of the thigh and is actively involved in knee extension. This muscle is the largest of the quadriceps muscle group (Drake et al. 2009).

### **5.2.2.3 Biceps Femoris Muscle (BF)**

The BF muscle resides in the posterior compartment of the thigh. This muscle forms part of the hamstring muscle group and is made up of two parts namely, the long and short head. The long head of the BF was investigated during this study. Both heads of the muscle are actively involved in knee flexion, while the long head of the BF also plays a role in hip extension (Drake et al. 2009).

### **5.2.3 Electromyography (EMG) to Torque Ratio**

The EMG to torque ratio describes the relationship between muscle activity and force (Table 5.1). This ratio may be used as a technique for assessing muscular endurance and adaptation to fatigue (Brown & Hahn 2005; Eguchi 2004).

### **5.2.4 Muscle Volume And Cross- Sectional Area**

The lean thigh volume (LTV) was calculated for both the involved and uninvolved limb prior to and following the rehabilitation interventions. This technique for estimating LTV assumes the upper section of the lower limb has the shape of a truncated cone and was adapted from the technique described by Katch and Katch, (1974). The LTV was calculated as described in section 3.2.3.

### **5.2.5 Statistical Analysis**

Data were analysed as described in section 3.3.

## 5.3 RESULTS

### 5.3.1 Isokinetic Strength Assessment

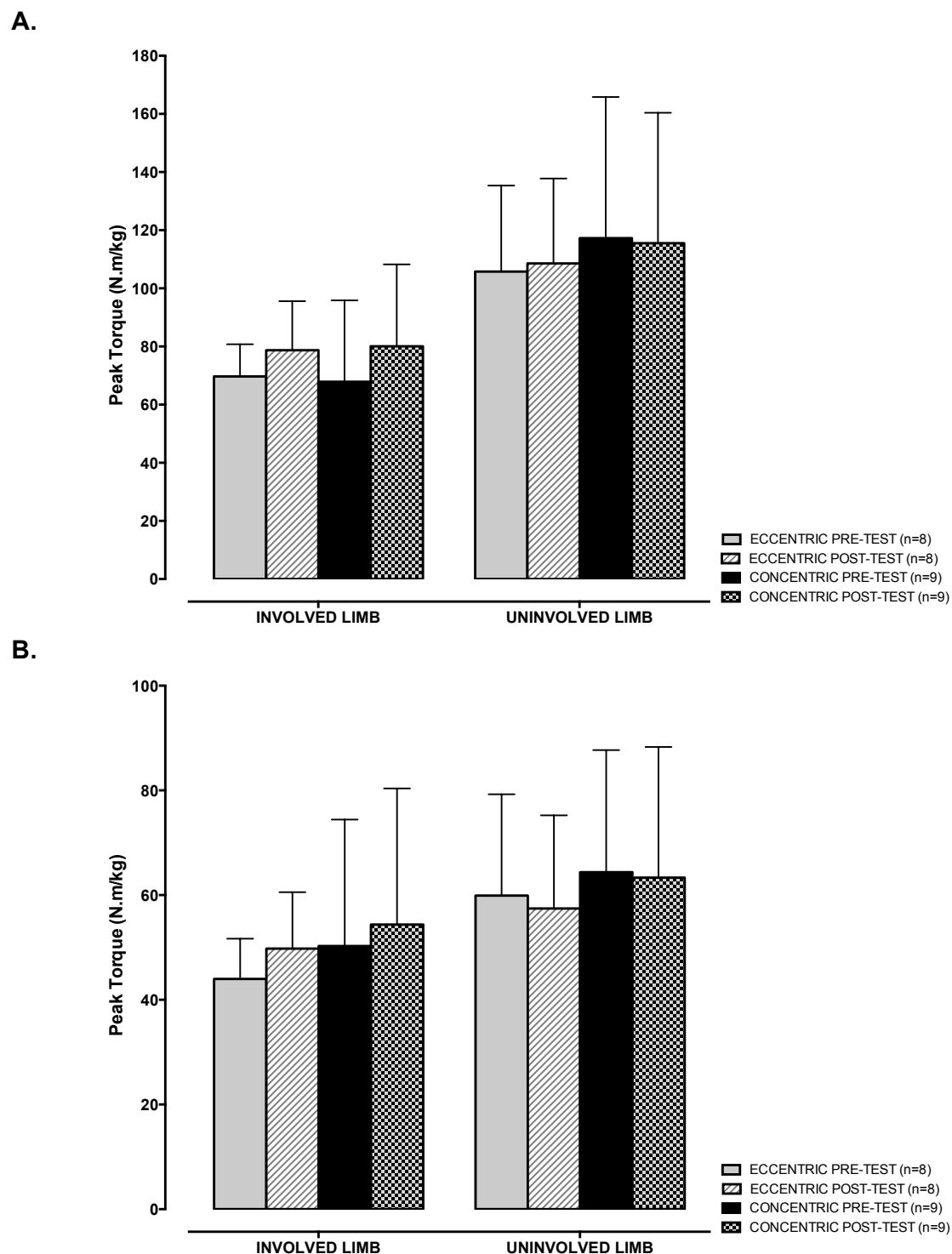
#### 5.3.1.1 Peak Torque Per Body Weight

There were no significant differences in the pre- to post-intervention change in peak torque (PTQ/BW) between the ECC group and the CON group for the involved limb (Extension: ECC group +9.04 N.m/kg, CON group +12.16 N.m/kg,  $P= 0.521$ ; Flexion: ECC group +5.78 N.m/kg, CON group +4.11 N.m/kg,  $P= 0.709$ ) and uninjured limb (Extension: ECC group +2.81 N.m/kg, CON group -1.76 N.m/kg,  $P= 0.567$ ; Flexion: ECC group -2.46 N.m/kg, CON group -1.04 N.m/kg,  $P= 0.834$ ) (Figure 5.1).

Neither the ECC group, nor the CON group significantly increased PTQ/BW of the involved limb (ECC group: Extension  $P= 0.226$ , Flexion,  $P= 0.237$ ; CON group: Extension;  $P= 0.372$ ; Flexion,  $P= 0.733$ ) and the uninjured limb (ECC group: Extension  $P= 0.851$ , Flexion  $P= 0.795$ ; CON group: Extension  $P= 0.937$ , Flexion  $P= 0.928$ ) from the pre to the post-intervention test.

The effect sizes for the pre- to post-intervention change in PTQ/BW were characterised as trivial to small differences for the involved limb (Extension  $ES= 0.11$ ; Flexion  $ES= 0.07$ ) and the uninjured limb (Extension  $ES= 0.09$ ; Flexion  $ES= 0.06$ ), between the ECC and CON groups.

The effect size for the change in the PTQ/BW of the ECC group was characterised as a small to moderate difference for the involved limb (Extension ES= 0.65; Flexion ES= 0.63), and a trivial to small difference for the uninvolved limb (Extension ES= 0.10; Flexion, ES= 0.13) from the pre- to post-intervention test. The effect size for the change in the PTQ/BW of the CON group was characterised as a trivial to small difference for the involved limb (Extension ES= 0.43; Flexion ES= 0.16) and the uninvolved limb (Extension ES= 0.04; Flexion ES= 0.04), from the pre- to post-intervention test.



**Figure 5.1. A)** A comparison of the PTQ/BW produced during knee extension, between the ECC and CON intervention group. **B)** A comparison of the PTQ/BW produced during knee flexion, between the ECC and CON intervention group. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; N.m/kg, Newton meters per kilogram.

### 5.3.1.2 Time To Peak Torque

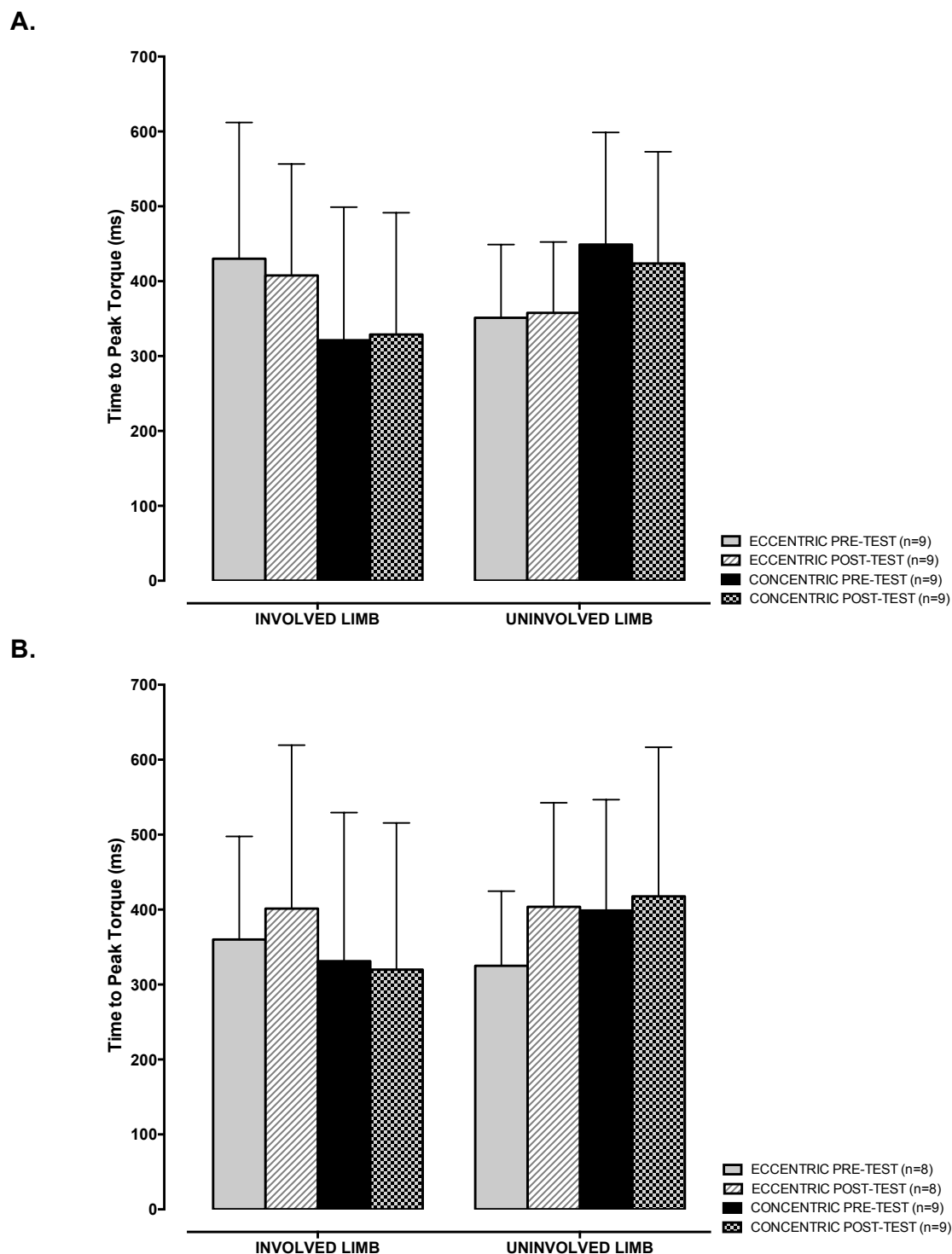
There were no significant differences in the pre- to post-intervention change in time to peak torque (TtPTQ) between the ECC group and the CON group for their involved limb (Extension: ECC group -22.22 ms, CON group +30.00 ms,  $P= 0.274$ ; Flexion: ECC group +41.25 ms, CON group +2.22 ms,  $P= 0.627$ ) and uninjured limb (Extension: ECC group +6.67 ms, CON group -18.89 ms,  $P= 0.669$ ; Flexion: ECC group +78.75 ms, CON group +28.75 ms,  $P= 0.485$ ) (Figure 5.2).

There were no significant changes in TtPTQ as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group: Extension  $P= 0.780$ , Flexion  $P= 0.658$ ; CON group: Extension  $P= 0.729$ , Flexion  $P= 0.981$ ) and the uninjured limb (ECC group: Extension  $P= 0.885$ , Flexion  $P= 0.213$ ; CON group: Extension  $P= 0.786$ , Flexion  $P= 0.757$ ) from the pre to the post-intervention test.

The effect sizes for the pre- to post-intervention change in TtPTQ were characterised as trivial to small differences for the involved limb (Extension  $ES= 0.30$ ; Flexion  $ES= 0.21$ ) and the uninjured limb (Extension  $ES= 0.17$ ; Flexion  $ES= 0.34$ ) between the ECC and CON groups.

The effect size for the change in TtPTQ of the ECC group was characterised as a small to moderate difference in knee flexion for involved limb ( $ES= 0.66$ ) and a trivial to small difference in knee extension for the involved limb ( $ES= 0.13$ ), from the pre- to post-intervention test. The effect size for the change in TtPTQ in the uninjured

limb of the ECC group was characterised as a trivial to small difference (Extension ES= 0.07; Flexion, ES= 0.09), from the pre- to post-intervention test. The effect size for the change in TtPTQ of the CON group was characterised as a trivial to small difference for the involved limb (Extension ES= 0.18; Flexion ES= 0.01) and the uninvolved limb (Extension ES= 0.13; Flexion ES= 0.16), from the pre- to post-intervention test.



**Figure 5.2. A)** A comparison of the TtPTQ produced during knee extension, between the ECC and CON intervention group. **B)** A comparison of the TtPTQ produced during knee flexion, between the ECC and CON intervention group over time. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; ms, milliseconds.

### 5.3.1.3 Torque At 30 Degrees

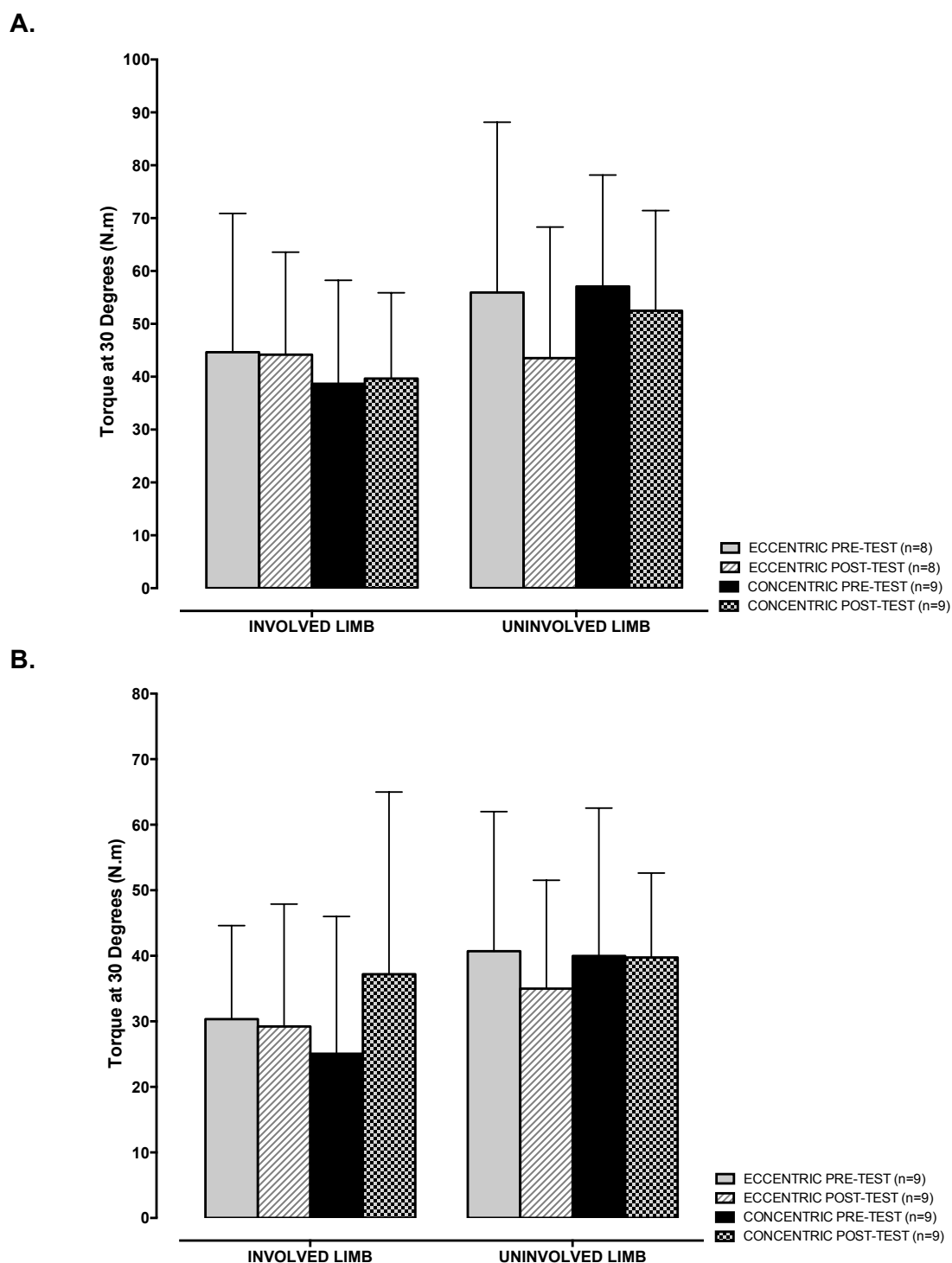
There were no significant differences in the pre- to post-intervention change in torque at 30 degrees (TQ30°) between the ECC group and the CON group for their involved limb (Extension: ECC group +5.89 N.m, CON group +1.00 N.m, P= 0.290; Flexion: ECC group -1.13 N.m, CON group +12.14 N.m, P= 0.226) and uninjured limb (Extension: ECC group -5.49 N.m, CON group -4.60 N.m, P= 0.909; Flexion: ECC group -5.71 N.m, CON group -0.23 N.m, P= 0.504) (Figure 5.3).

Neither the ECC group, nor the CON group significantly increased TQ30° of the involved limb (ECC group: Extension P= 0.552, Flexion P= 0.894; CON group: Extension P= 0.908, Flexion P= 0.311) and the uninjured limb (ECC group: Extension P= 0.674, Flexion P= 0.558; CON group: Extension P= 0.633, Flexion P= 0.979) from the pre to the post-intervention test.

The effect sizes for the pre- to post-intervention change in TQ30° during knee flexion were characterised as a small to moderate difference (Involved Limb ES= 0.63) between the ECC and CON groups. The effect sizes for the pre- to post-intervention change in TQ30° were characterised as trivial to small differences during knee extension (Involved Limb ES= 0.25; Uninvolved Limb ES= 0.04) and knee flexion (Uninvolved Limb ES= 0.24) between the ECC and CON groups.

The effect size for the change in the TQ30° of the ECC group was characterised as a small to moderate difference for knee flexion of the uninjured limb (ES= 0.55), and a trivial to small difference for the involved limb (Extension ES= 0.30; Flexion ES=

0.07) and knee extension of uninvolved limb (ES= 0.21), from the pre- to post-intervention test. The effect size for the change in the TQ30° of the CON group was characterised as a small to moderate difference for knee flexion of the involved limb (ES= 0.50), and a trivial to small difference for the uninvolved limb (Extension ES= 0.23; Flexion ES= 0.01) and knee extension of involved limb (ES= 0.06), from the pre- to post-intervention test.



**Figure 5.3. A)** A comparison of the  $TQ_{30^\circ}$  produced during knee extension, between the ECC and CON intervention group. **B)** A comparison of the  $TQ_{30^\circ}$  produced during knee flexion, between the ECC and CON intervention group over time. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; N.m, Newton meters.

### 5.3.1.4 Total Work

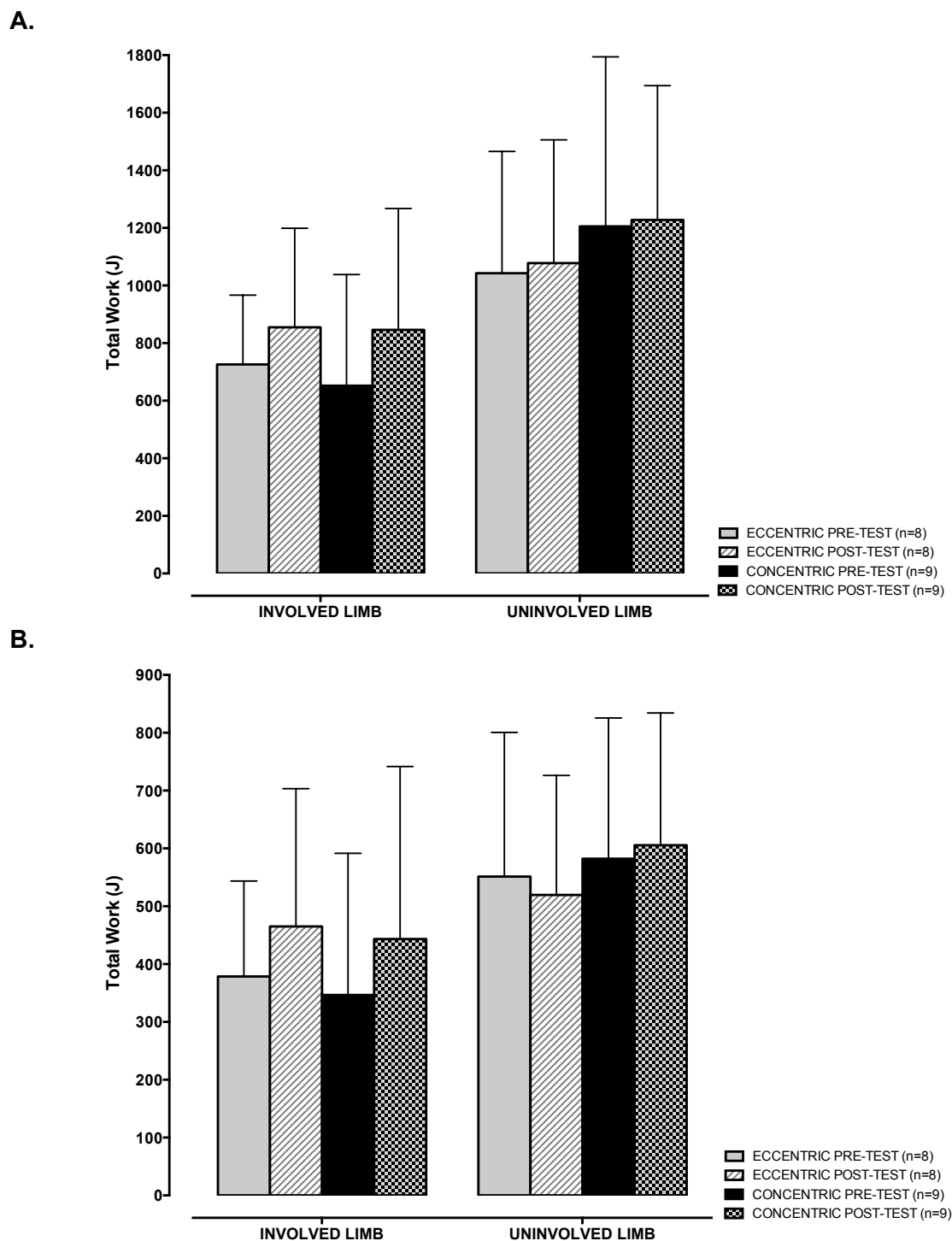
There were no significant differences in the pre- to post-intervention change in total work (TotW) between the ECC group and the CON group for their involved limb (Extension: ECC group +129.08 J, CON group +194.90 J,  $P= 0.449$ ; Flexion: ECC group +86.66 J, CON group +96.79 J,  $P= 0.846$ ) and uninvolved limb (Extension: ECC group +35.19 J, CON group +22.28 J,  $P= 0.882$ ; Flexion: ECC group -31.80 J, CON group +23.24 J,  $P= 0.271$ ) (Figure 5.4).

There were no significant changes in TotW as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group: Extension  $P= 0.399$ , Flexion  $P= 0.412$ ; CON group: Extension  $P= 0.200$ , Flexion  $P= 0.463$ ) and the uninvolved limb (ECC group: Extension  $P= 0.871$ , Flexion  $P= 0.785$ ; CON group: Extension  $P= 0.930$ , Flexion  $P= 0.837$ ) from the pre to the post-intervention test.

The effect sizes for the pre- to post-intervention change in TotW during knee flexion (Involved Limb  $ES= 0.04$ ; Uninvolved Limb  $ES= 0.23$ ) and knee extension (Involved Limb  $ES= 0.26$ ; Uninvolved Limb  $ES= 0.02$ ) were characterised as trivial to small differences between the ECC and CON groups.

The effect size for the change in the TotW of the ECC group was characterised as a trivial to small difference for the involved limb (Extension  $ES= 0.44$ ; Flexion  $ES= 0.43$ ) and the uninvolved limb (Extension  $ES= 0.08$ ; Flexion  $ES= 0.14$ ), from the pre- to post-intervention test. The effect size for the change in the TotW of the CON group was characterised as a small to moderate difference for knee extension of the

involved limb (ES= 0.68), and a trivial to small difference for the uninvolved limb (Extension ES= 0.04; Flexion ES= 0.10) and knee flexion of involved limb (ES= 0.36), from the pre- to post-intervention test.



**Figure 5.4. A)** A comparison of the TotW produced during knee extension, between the ECC and CON intervention group. **B)** A comparison of the TotW produced during knee flexion, between the ECC and CON intervention group over time. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; J, joules.

### 5.3.1.5 Work Fatigue

There were no significant differences in the pre- to post-intervention change in work fatigue (WF) between the ECC group and the CON group for their involved limb (Extension: ECC group +7.77%, CON group -7.34%,  $P= 0.101$ ; Flexion: ECC group +3.48%, CON group -3.74%,  $P= 0.553$ ) and uninvolved limb (Extension: ECC group +3.14%, CON group -5.57%,  $P= 0.196$ ; Flexion: ECC group +6.01%, CON group +0.70%,  $P= 0.662$ ) (Figure 5.5).

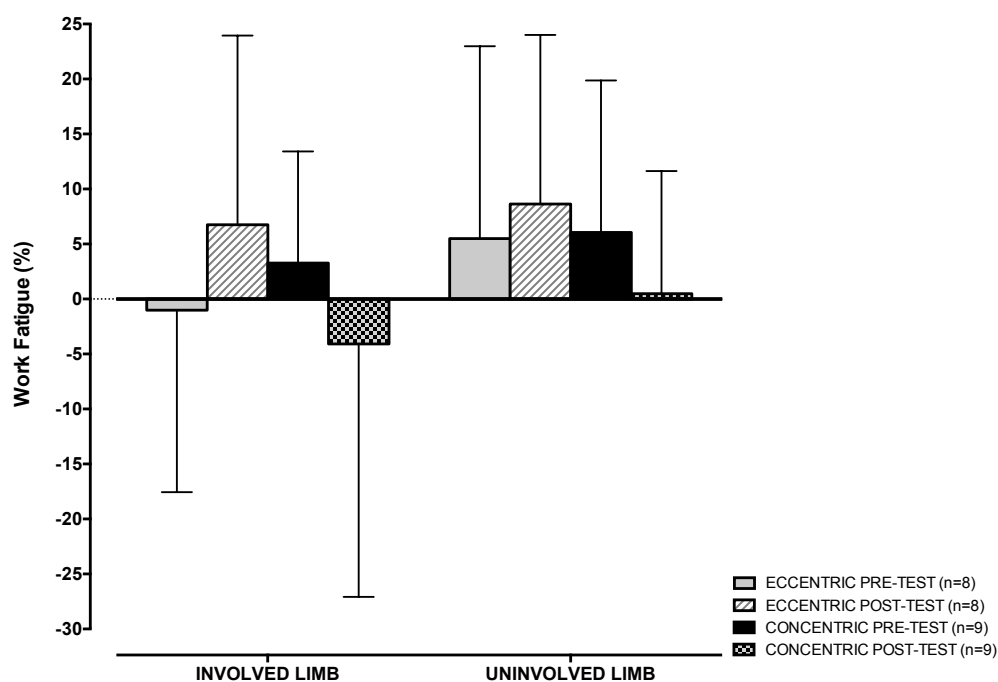
There were no significant changes in WF as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group: Extension  $P= 0.343$ , Flexion  $P= 0.724$ ; CON group: Extension  $P= 0.394$ , Flexion  $P= 0.783$ ) and the uninvolved limb (ECC group: Extension  $P= 0.690$ , Flexion  $P= 0.475$ ; CON group: Extension  $P= 0.361$ , Flexion  $P= 0.958$ ) from the pre to the post-intervention test.

The effect size for the pre- to post-intervention change in WF during knee extension of the involved limb was characterised as a large difference ( $ES= 1.49$ ) between the ECC and CON groups. The effect sizes for the pre- to post-intervention change in WF during knee flexion (Involved Limb  $ES= 0.29$ ; Uninvolved Limb  $ES= 0.15$ ) and knee extension of the uninvolved limb ( $ES= 0.63$ ) were characterised as trivial to small differences between the ECC and CON groups.

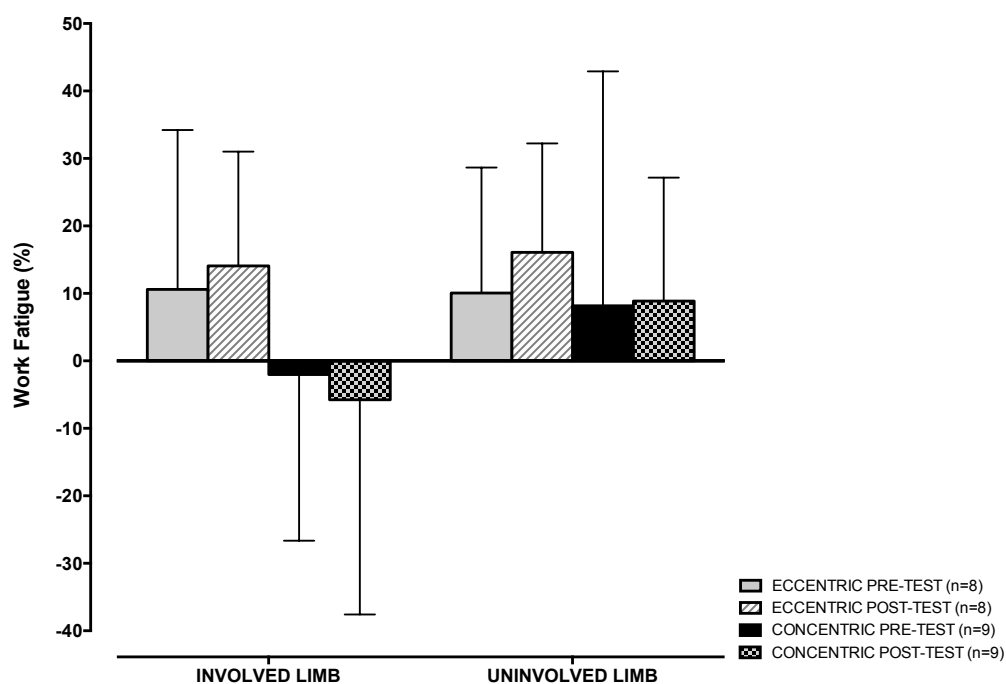
The effect size for the change in the WF of the ECC group was characterised as a trivial to small difference for the involved limb (Extension  $ES= 0.46$ ; Flexion  $ES= 0.17$ ) and the uninvolved limb (Extension  $ES= 0.19$ ; Flexion  $ES= 0.35$ ), from the pre-

to post-intervention test. The effect size for the change in the WF of the CON group was characterised as a trivial to small difference for the involved limb (Extension ES= 0.44; Flexion ES= 0.13) and the uninvolved limb (Extension ES= 0.45; Flexion ES= 0.03), from the pre- to post-intervention test.

A.



B.



**Figure 5.5.** A) A comparison of the percentage of WF experienced during knee extension, between the ECC and CON intervention group. B) A comparison of the percentage of WF experienced during knee flexion, between the ECC and CON intervention group over time. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; %, percentage.

### **5.3.2 Electromyography**

EMG was recorded throughout the isokinetic strength testing trials. The EMG signal was taken from the following muscles: VM, VL and BF on both the involved and uninjured legs.

#### **5.3.2.1 The Vastus Medialis Muscle**

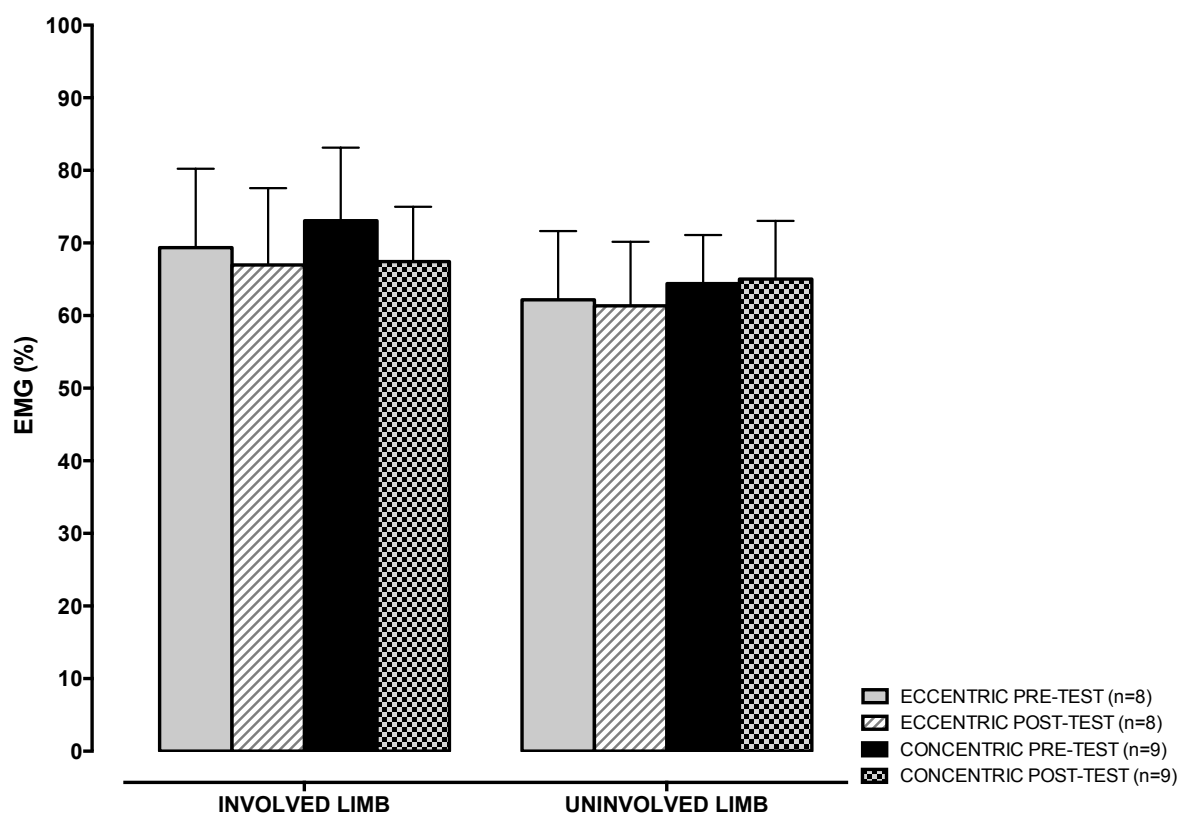
There were no significant differences in the pre- to post-intervention change in VM muscle activity between the ECC group and the CON group for their involved limb (ECC group -4.42%, CON group -5.63%,  $P= 0.807$ ) and uninjured limb (ECC group -2.01%, CON group +0.64%,  $P= 0.517$ ) (Figure 5.6).

There were no significant changes in VM muscle activity as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.877$ ; CON group  $P= 0.198$ ) and the uninjured limb (ECC group  $P= 0.649$ ; CON group  $P= 0.856$ ) from the pre to the post-intervention test.

The effect size for the pre- to post-intervention change in VM muscle activity of the involved limb ( $ES= 0.12$ ) and uninjured limb ( $ES= 0.26$ ) was characterised as a trivial to small differences between the ECC and CON groups.

The effect size for the change in the VM muscle activity of the ECC group was characterised as a trivial to small difference for the involved limb ( $ES= 0.44$ ) and the uninjured limb ( $ES= 0.22$ ), from the pre- to post-intervention test. The effect size for

the change in the VM muscle activity of the CON group was characterised as a small to moderate difference for the involved limb (ES= 0.64), and a trivial to small difference for the uninvolved limb (ES= 0.09), from the pre- to post-intervention test.



**Figure 5.6.** A comparison of the VM muscle activity between the ECC and CON intervention group. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants.

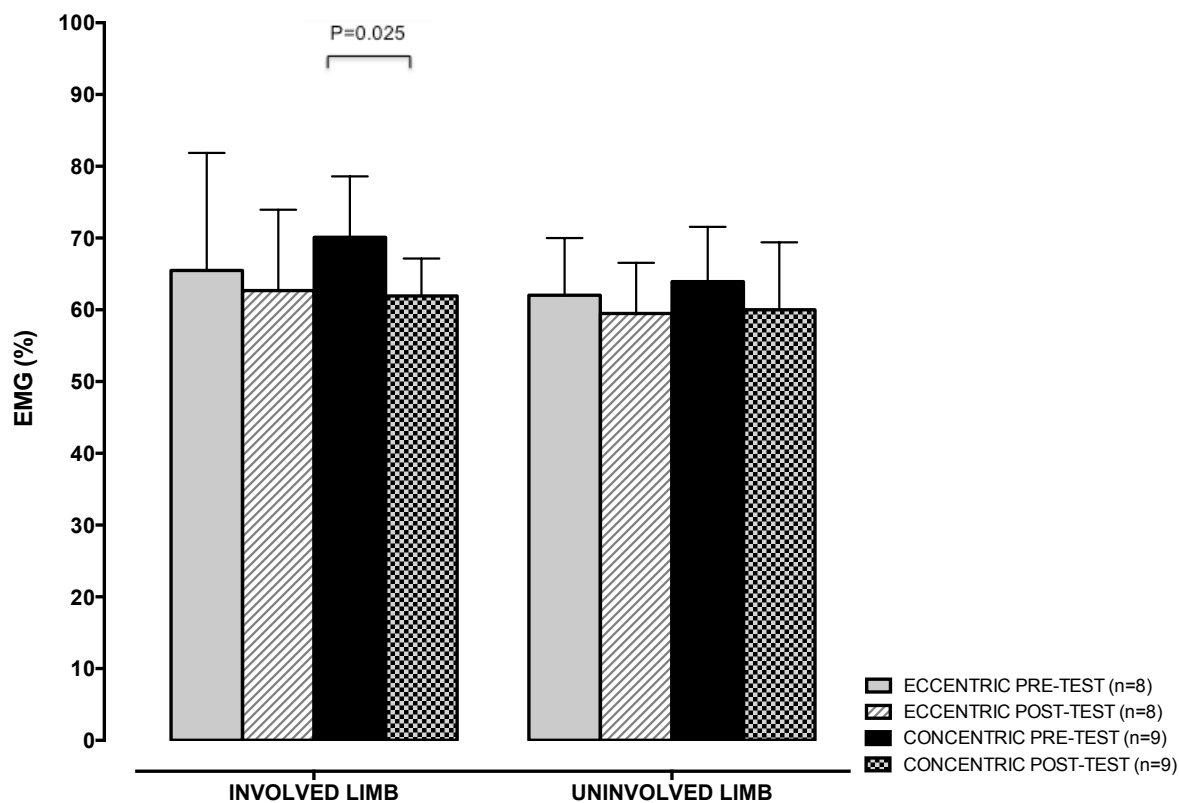
### 5.3.2.2 The Vastus Lateralis Muscle

There were no significant differences in the pre- to post-intervention change in VL muscle activity between the ECC group and the CON group for their involved limb (ECC group -4.93%, CON group -8.17%,  $P= 0.474$ ) and uninvolved limb (ECC group -3.47%, CON group -3.91%,  $P= 0.925$ ) (Figure 5.7).

The VL muscle activity in the involved limb of the CON group decreased significantly (Pre  $70.11\% \pm 8.48\%$ , Post  $61.94\% \pm 5.19\%$ ;  $P= 0.025$ ) following the concentric rehabilitation intervention. There were no further significant changes in VL muscle activity in the uninvolved limb ( $P= 0.347$ ) in the CON group and both limbs for the ECC group (Involved Limb  $P= 0.472$ ; Uninvolved Limb  $P= 0.369$ ).

The effect size for the pre- to post-intervention change in VL muscle activity of the involved limb ( $ES= 0.38$ ) and uninvolved limb ( $ES= 0.06$ ) was characterised as a trivial to small differences between the ECC and CON groups.

The effect size for the change in the VL muscle activity of the ECC group was characterised as a small difference for the involved limb ( $ES= 0.35$ ) and the uninvolved limb ( $ES= 0.46$ ), from the pre- to post-intervention test. The effect size for the change in the VL muscle activity of the CON group was characterised as a moderate to large difference for the involved limb ( $ES= 1.19$ ), and a small difference for the uninvolved limb ( $ES= 0.46$ ), from the pre- to post-intervention test.



**Figure 5.7.** A comparison of the VL muscle activity between the ECC and CON intervention group. Abbreviations ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants.

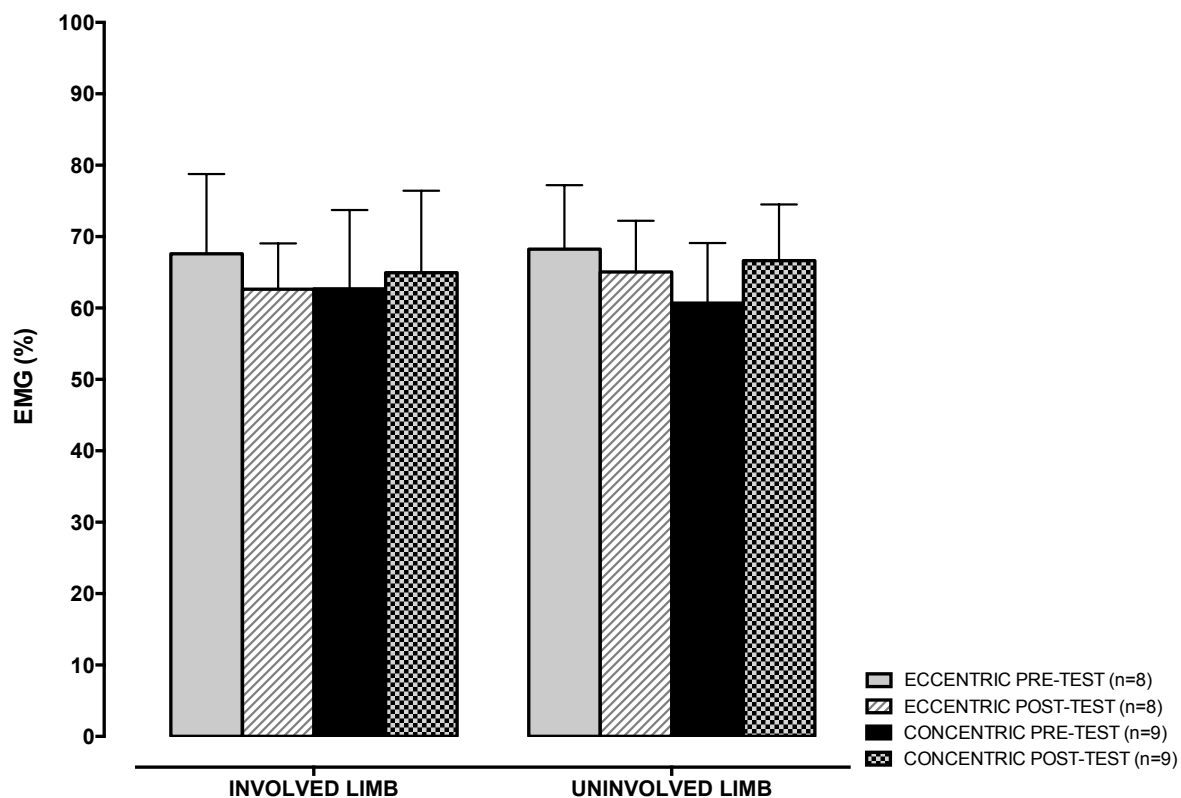
### 5.3.2.3 The Biceps Femoris Muscle

There was a tendency towards a significant difference in the pre- to post-intervention change in BF muscle activity between the ECC group and the CON group in the uninvolved limb (ECC group -3.20%, CON group +5.73%,  $P= 0.058$ ), however there were no significant differences in the pre- to post-intervention change in BF muscle activity between the ECC group and the CON group in the involved limb (ECC group -4.96%, CON group +5.32%,  $P= 0.139$ ) (Figure 5.8).

There were no significant changes in BF muscle activity as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.265$ ; CON group  $P= 0.386$ ) and the uninvolved limb (ECC group  $P= 0.416$ ; CON group  $P= 0.196$ ) from the pre to the post-intervention test.

The effect size for the pre- to post-intervention change in BF muscle activity of the involved limb ( $ES= 0.93$ ) and uninvolved limb ( $ES= 0.99$ ) was characterised as a moderate difference between the ECC and CON groups.

The effect size for the change in the BF muscle activity of the ECC group was characterised as a small to moderate difference for the involved limb ( $ES= 0.56$ ) and the uninvolved limb ( $ES= 0.40$ ), from the pre- to post-intervention test. The effect size for the change in the BF muscle activity of the CON group was characterised as a moderate difference for the involved limb ( $ES= 0.73$ ), and a small to moderate difference for the uninvolved limb ( $ES= 0.68$ ), from the pre- to post-intervention test.



**Figure 5.8.** A comparison of the BF muscle activity between the ECC and CON intervention group. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants.

### **5.2.3 Electromyography (EMG) to Torque Ratio**

There were no significant differences in the pre- to post-intervention change in the EMG to Torque output (EMG/Torque) ratios between the ECC group and the CON group for the involved limb and uninvolved limb. There were no significant changes for the EMG/Torque ratios as a result of the respective interventions in either the ECC group or the CON group from the pre to the post-intervention test.

The effect size for the pre- to post-intervention change for the EMG/Torque ratios for the involved limb and uninvolved limb (VM, VL and BF) were characterised as a trivial to small difference between the ECC and CON groups (Table 5.1).

**Table 5.1: A comparison of the EMG to torque output ratio between the eccentric (ECC) and concentric (CON) intervention group.**

Muscle	Intervention Group									
	ECC Group (n=8)				CON Group (n=9)				ECC vs. CON	
	Pre-Test	Post-Test	P <sup>1</sup>		Pre-Test	Post-Test	P <sup>2</sup>		P <sup>3</sup>	ES
<b>Involves:</b>										
VM	1.03 ± 0.26	0.90 ± 0.29	0.357		1.49 ± 1.33	0.93 ± 0.30	0.228		0.331	0.33
VL	1.02 ± 0.43	0.86 ± 0.31	0.402		1.45 ± 1.38	0.87 ± 0.31	0.236		0.361	0.30
BF	1.53 ± 0.43	1.32 ± 0.36	0.292		1.63 ± 0.99	1.78 ± 1.53	0.801		0.174	0.37
<b>Uninvolved:</b>										
VM	0.59 ± 0.20	0.63 ± 0.26	0.766		0.66 ± 0.33	0.66 ± 0.32	0.999		0.866	0.10
VL	0.59 ± 0.21	0.60 ± 0.25	0.925		0.67 ± 0.42	0.59 ± 0.28	0.663		0.578	0.21
BF	1.30 ± 0.62	1.24 ± 0.48	0.816		1.10 ± 0.56	1.05 ± 0.63	0.851		0.974	0.02

<sup>1</sup>: ECC Pre vs. ECC Post-Test; <sup>2</sup>: CON Pre vs. CON Post-Test; <sup>3</sup>: ECC vs. CON; ES, ECC vs. CON. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; P, P-value; ES, effect size; VM, vastus medialis; VL, vastus lateralis; BF, biceps femoris. Significant values are shown with bold typeset.

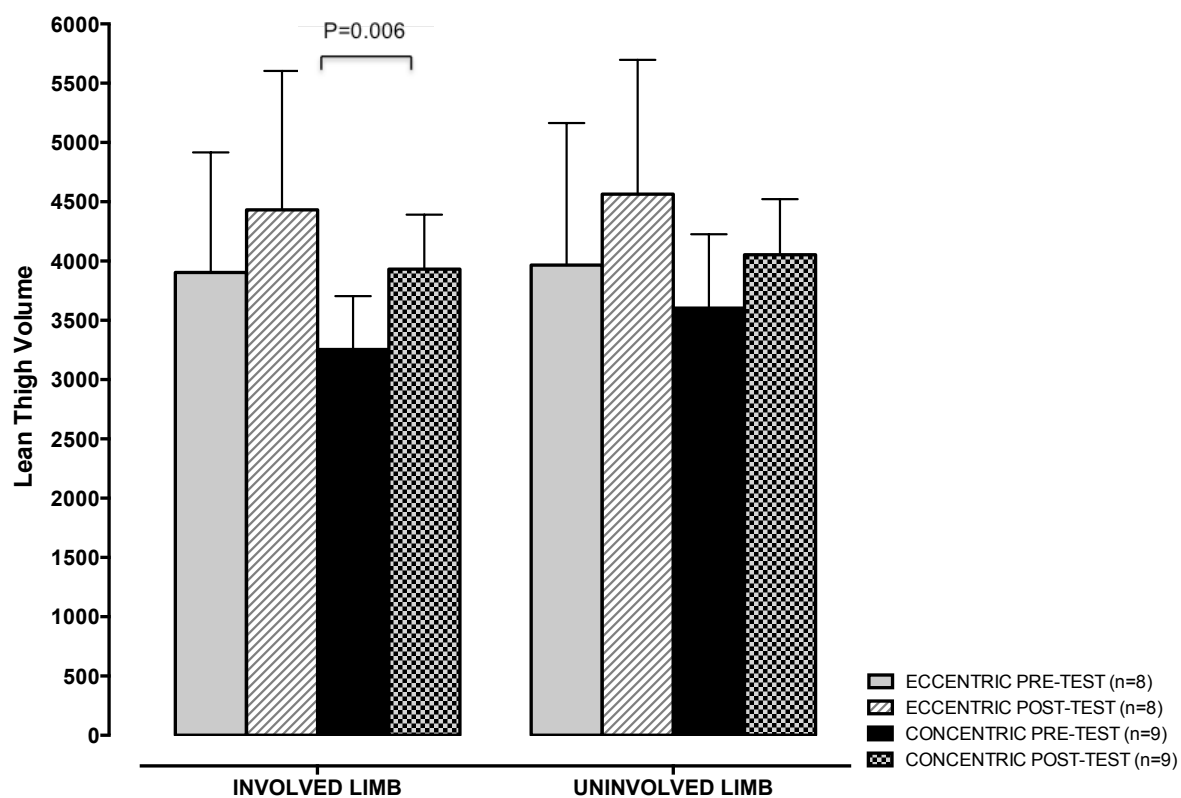
### **5.3.4 Muscle Volume And Cross- Sectional Area**

There were no significant differences in the pre- to post-intervention change in lean thigh volume (LTV) between the ECC group and the CON group for their involved limb (ECC group +648.96, CON group +677.49,  $P= 0.896$ ) and uninvolved limb (ECC group +807.32, CON group +449.41,  $P= 0.202$ ) (Figure 5.9).

The LTV in the involved limb of the CON group increased significantly (Pre,  $3254.44 \pm 449.71$ ; Post,  $3931.93 \pm 459.56$ ;  $P= 0.006$ ) following the concentric rehabilitation intervention. There were no further significant changes in LTV in the uninvolved limb ( $P= 0.103$ ) of the CON group and both limbs for the ECC group (Involved Limb,  $P= 0.223$ ; Uninvolved Limb,  $P= 0.168$ ).

The effect size for the pre- to post-intervention change in LTV of the involved limb ( $ES= 0.03$ ) and uninvolved limb ( $ES= 0.57$ ) was characterised as a trivial to small differences between the ECC and CON groups.

The effect size for the change in the LTV of the ECC group was characterised as a moderate difference for the uninvolved limb ( $ES= 0.73$ ) and a small to moderate difference for the involved limb ( $ES= 0.60$ ), from the pre- to post-intervention test. The effect size for the change in the LTV of the CON group was characterised as a large difference for the involved limb ( $ES= 1.49$ ), and a moderate difference for the uninvolved limb ( $ES= 0.82$ ), from the pre- to post-intervention test.



**Figure 5.9.** A comparison of the LTV between the ECC and CON intervention group. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants.

## 5.4 DISCUSSION

The primary objective of this study was to investigate changes in muscular strength and endurance, muscle activity and muscle volume after performing either an eccentric or concentric biased rehabilitation intervention. The findings related to muscular strength and endurance, muscular activity and muscle area are summarised in Table 5.2 and 5.3, respectively.

The eccentric rehabilitation intervention did not result in statistically significant improvements in quadriceps and hamstring muscular strength and endurance. When the muscle activity and lean thigh volume was compared, only the concentric rehabilitation intervention resulted in a statistically significant decrease in the VL muscle activity, as well as a significant increase in the lean thigh volume (LTV) in the involved limb. However, there was a moderate increase in the LTV of the uninvolved limb of both the eccentric (ECC) and concentric (CON) intervention groups. No other variables were statistically different. When muscle activity was compared between the two groups, although only a statistical tendency existed for the uninvolved limb, there were moderate effects for the difference in BF muscle activity between the ECC and CON intervention groups in both the involved and uninvolved limb. Further, there was a moderate effect for BF muscle activity to increase in the involved limb within the CON group.

**Table 5.2: Summary of muscular strength and endurance differences within the intervention groups across the intervention period for either the eccentric (ECC) or concentric (CON) intervention group, as well as difference between the intervention groups (ECC vs. CON).**

Variable:	Intervention Group									
	ECC Group (n=8)					CON Group (n=9)				
	P <sup>1</sup>	ES <sup>1</sup>	Descriptor	P <sup>2</sup>	ES <sup>2</sup>	Descriptor	P <sup>3</sup>	ES <sup>3</sup>	Descriptor	
<b>Peak Torque</b>										
Knee Extension:	Involved: 0.226	0.65	Small / Moderate	0.372	0.43	Small	0.521	0.11	Trivial / Small	
	Uninvolved: 0.851	0.10	Trivial / Small	0.937	0.04	Trivial	0.567	0.09	Trivial	
Knee Flexion:	Involved: 0.237	0.63	Small / Moderate	0.733	0.16	Trivial / Small	0.709	0.07	Trivial	
	Uninvolved: 0.795	0.13	Trivial / Small	0.928	0.04	Trivial	0.834	0.06	Trivial	
<b>Time to Peak Torque</b>										
Knee Extension:	Involved: 0.780	0.13	Trivial / Small	0.729	0.18	Trivial	0.274	0.30	Trivial / Small	
	Uninvolved: 0.885	0.07	Trivial	0.786	0.13	Trivial / Small	0.669	0.17	Trivial / Small	
Knee Flexion:	Involved: 0.658	0.66	Small / Moderate	0.981	0.01	Trivial	0.627	0.21	Trivial / Small	
	Uninvolved: 0.213	0.09	Trivial	0.757	0.16	Trivial / Small	0.485	0.34	Small	
<b>Torque at 30°</b>										
Knee Extension:	Involved: 0.552	0.30	Trivial / Small	0.908	0.06	Trivial	0.290	0.25	Trivial / Small	
	Uninvolved: 0.674	0.21	Trivial / Small	0.633	0.23	Trivial / Small	0.909	0.24	Trivial / Small	
Knee Flexion:	Involved: 0.894	0.07	Trivial	0.311	0.50	Small / Moderate	0.226	0.63	Small / Moderate	
	Uninvolved: 0.558	0.55	Small / Moderate	0.979	0.01	Trivial	0.504	0.53	Small / Moderate	
<b>Total Work</b>										
Knee Extension:	Involved: 0.399	0.44	Small	0.200	0.68	Small / Moderate	0.449	0.26	Trivial / Small	
	Uninvolved: 0.871	0.08	Trivial	0.930	0.04	Trivial	0.882	0.02	Trivial	
Knee Flexion:	Involved: 0.412	0.43	Trivial / Small	0.463	0.36	Small	0.846	0.04	Trivial	
	Uninvolved: 0.785	0.14	Trivial / Small	0.837	0.10	Trivial / Small	0.271	0.23	Trivial / Small	
<b>Work Fatigue</b>										
Knee Extension:	Involved: 0.343	0.46	Small	0.394	0.44	Small	0.101	<b>1.49</b>	<b>Large</b>	
	Uninvolved: 0.690	0.19	Trivial / Small	0.361	0.45	Small	0.196	0.63	Trivial / Small	
Knee Flexion:	Involved: 0.724	0.17	Trivial / Small	0.783	0.13	Trivial / Small	0.553	0.29	Trivial / Small	
	Uninvolved: 0.226	0.65	Small / Moderate	0.372	0.43	Small	0.662	0.15	Trivial / Small	

<sup>1</sup>: ECC Pre vs. ECC Post-Test; <sup>2</sup>: CON Pre vs. CON Post-Test; <sup>3</sup>: ECC vs. CON. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; P, P-value; ES, effect size. Significant values are shown with bold typeset.

**Table 5.3: Summary of muscle activity and lean thigh volume differences within the intervention groups across the intervention period for either the eccentric (ECC) or concentric (CON) intervention group, as well as difference between the intervention groups (ECC vs. CON).**

Variable:	Intervention Group												
	ECC Group (n=8)					CON Group (n=9)					ECC vs. CON		
	P <sup>1</sup>	ES <sup>1</sup>	Descriptor	P <sup>2</sup>	ES <sup>2</sup>	Descriptor	P <sup>3</sup>	ES <sup>3</sup>	Descriptor	P <sup>3</sup>	ES <sup>3</sup>	Descriptor	
<b>Electromyography</b>													
Vastus medialis:	Involved:	0.877	0.44	Small	0.198	0.64	Small / Moderate	0.807	0.12	Trivial / Small	0.807	0.12	Trivial / Small
	Uninvolved:	0.649	0.22	Trivial / Small	0.856	0.09	Trivial	0.517	0.26	Trivial / Small	0.517	0.26	Trivial / Small
Vastus lateralis:	Involved:	0.472	0.35	Small	<b>0.025</b>	<b>1.19</b>	<b>Moderate / Large</b>	0.474	0.38	Small	0.474	0.38	Small
	Uninvolved:	0.369	0.46	Small	0.347	0.46	Small	0.925	0.06	Trivial	0.925	0.06	Trivial
Biceps femoris:	Involved:	0.265	0.56	Small / Moderate	0.416	<b>0.73</b>	<b>Moderate</b>	0.139	<b>0.93</b>	<b>Moderate</b>	0.139	<b>0.93</b>	<b>Moderate</b>
	Uninvolved:	0.386	0.40	Small	0.196	0.68	Small / Moderate	0.058	<b>0.99</b>	<b>Moderate</b>	0.058	<b>0.99</b>	<b>Moderate</b>
<b>Lean Thigh Volume</b>	Involved:	0.223	0.60	Small / Moderate	<b>0.006</b>	<b>1.49</b>	<b>Large</b>	0.896	0.03	Trivial	0.896	0.03	Trivial
	Uninvolved:	0.168	<b>0.73</b>	<b>Moderate</b>	0.103	<b>0.82</b>	<b>Moderate</b>	0.202	0.57	Small / Moderate	0.202	0.57	Small / Moderate

<sup>1</sup>: ECC Pre vs. ECC Post-Test; <sup>2</sup>: CON Pre vs. CON Post-Test; <sup>3</sup>: ECC vs. CON. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; P, P-value; ES, effect size. Significant values are shown with bold typeset.

Endurance was assessed by the ratio of work performed in the first and last third of the isokinetic strength test. The effect size for the pre- to post-intervention change in work fatigue (WF) during knee extension of the involved limb was large between the ECC and CON group, with the ECC group demonstrating greater fatigue. This result suggests that the concentric rehabilitation intervention resulted in greater gains in muscle endurance in comparison to the eccentric rehabilitation intervention.

The moderate reduction in BF muscle activity of the ECC intervention in comparison to the CON intervention suggests that the eccentric training resulted in improved muscle efficiency, whereby the hamstring muscle group is able to produce the same amount of force during knee flexion, with a reduction in BF muscle activity. Additionally, the eccentric intervention resulted in a moderate decrease in BF muscle activity of the involved limb from the pre- to post-intervention test, while maintaining the same force output during knee flexion. This result suggests that there was a tendency for the eccentric rehabilitation intervention to promote improvements in BF muscle efficiency, which may lead to enhanced movement efficacy and joint protection.

The VL muscle activity in the involved limb of the CON group decreased significantly following the concentric rehabilitation intervention. Correspondingly, the effect size shows that the concentric intervention resulted in a moderate to large decrease in VL muscle recruitment of the involved limb from the pre- to post-intervention test. This result implies that, as a result of the concentric intervention, the CON group is able to produce an equal amount of force with a reduction in VL muscle recruitment, suggesting an increase in muscle efficiency.

Additionally, the LTV in the involved limb of the CON group significantly increased following the concentric rehabilitation intervention, although there were no significant changes in force production, or any significant differences between the intervention groups. Correspondingly, the effect size shows that the concentric intervention resulted in a large increase in the LTV of the involved limb and a moderate increase in the uninvolved limb from the pre- to post-intervention test. Similarly, the ECC group showed a moderate increase in the LTV in the uninvolved limb from the pre- to post-intervention test. A possible explanation for this result might be that during the rehabilitation intervention, the participants relied more heavily on the uninvolved limb to perform the work as an attempt to compensate for existing weakness in the involved limb. Previous research suggests that either eccentric or concentric training performed separately can promote increases in muscle mass. However, eccentric training performed at a higher level of intensity appears to be more effective at increasing muscle mass in comparison to concentric training (Roig et al. 2009). In this particular study, the rehabilitation interventions were matched in both duration and perceived exertion (RPE) and this may serve as an explanation as to why there were no significant differences between the intervention groups.

A number of research studies suggest that adaptation to concentric and eccentric training is highly dependent on the muscle action used for training and testing, whereby eccentric training results in eccentric strength improvements and concentric training results in concentric strength improvements (Miller et al. 2006; Hortobágyi et al. 2000; Higbie et al. 1996; Duncan et al. 1989; Tomberlin et al. 1991; Seger et al. 1998). In addition to previous study reports on specificity, a systematic review conducted by Roig et al. (2009) provides evidence that strength gains from eccentric

training are also velocity-dependent and therefore the high specificity of eccentric exercise has to be taken into account when gains in total strength are interpreted. Additionally, a meta analysis conducted by Roig et al. (2009) indicated that subgroup analyses of three studies in which intensity was equated as a percentage of one repetition-maximum (1RM) during concentric training showed no major differences between eccentric and concentric training in promoting gains in strength. In contrast, eccentric training performed at high intensities was more effective in promoting increases in muscle mass measured as muscle girth. Thus, although eccentric training seems an effective means of restoring knee function, no study, to our knowledge has compared eccentric to concentric training or rehabilitation interventions, which are matched in duration and perceived exertion in participants as early as three months post-TKA. This may serve as an explanation as to why there were no significant differences in strength gains following the rehabilitation interventions. Additionally, the lack of significant differences between groups may also be attributable to the relatively small sample size. Alternatively, existing physical and functional limitations within the patient population may delay or hinder improvements in strength related outcomes.

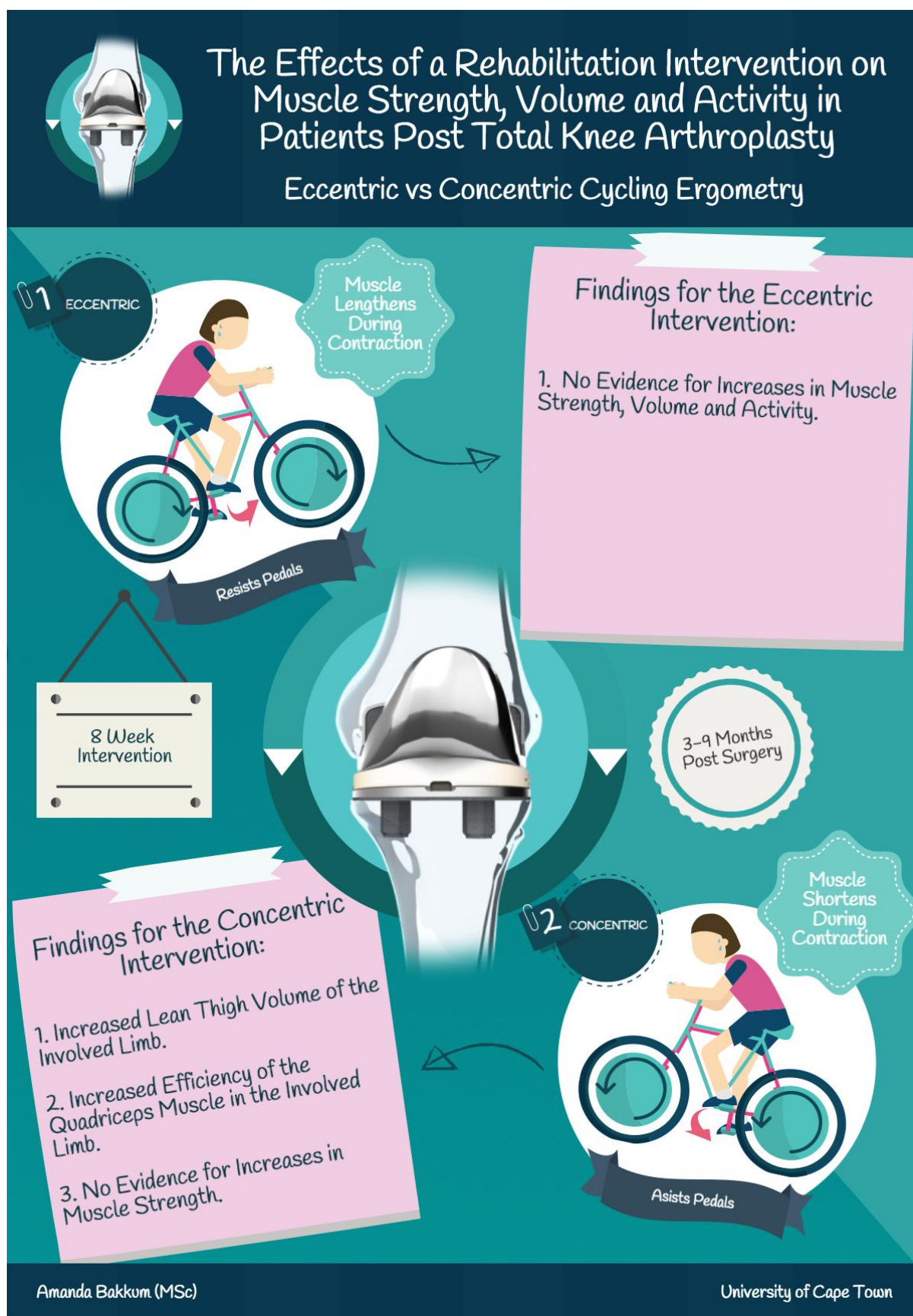
According to the normative values available for peak torque (PTQ/BW) during knee extension, the forces produced by both the ECC and CON groups fall well below the normative value range prior to and following the rehabilitation interventions. These results demonstrate that despite the rehabilitation interventions; both the ECC and CON group's strength outputs do not reach those of age-matched individuals and strength deficits remain. This supports existing research suggesting that although strength improvements may occur, it rarely reaches that of age-matched individuals

with non-arthritic knees or that of the uninvolved limb (Berth et al. 2002; Yoshida et al. 2008).

The limitations of this study included standard deviations that were larger than expected due to the heterogeneity of the patient population. These high standard deviations could play a role in the few statistically significant changes found in this study. Therefore, effect size calculations were performed in order to characterise the clinical significance as opposed to the statistically significant differences in the strength related outcomes of the rehabilitation intervention and between groups, which accounts for the high standard deviations on the overall results. A further limitation to this study was the absence of eccentric isokinetic strength testing. It is suggested that future studies should investigate larger populations or investigate a more homogenous population of participants, as well as include both concentric and eccentric isokinetic strength testing when comparing these two modes of exercise.

In conclusion, this study suggests that compared with concentric training, eccentric training performed with matched perceived exertion may be associated with greater improvements in hamstring (knee flexion) muscle efficiency during concentric contractions. Alternatively, concentric training may be associated with greater gains in muscle area and quadriceps (knee extension) muscle efficiency during concentric contractions (Figure 5.10).

It is important to note that strength gains after eccentric training are highly specific to the mode of contraction as well as the intensity of training. Additionally, the neural specificity of eccentric exercise may compromise the transferability of strength gains to concentric type muscle movements. Further research is required to investigate the extent to which training specificity influences the transferability of strength gains to activities of daily living.



**Figure 5.10.** An infographic summarising the conclusions of Study 2.



**CHAPTER 6****STUDY 3: THE EFFECT OF AN ECCENTRIC VERSUS CONCENTRIC CYCLING  
ERGOMETRY REHABILITATION INTERVENTION ON SELF REPORT PHYSICAL  
AND MENTAL HEALTH SURVEYS IN PATIENTS POST TOTAL KNEE  
ARTHROPLASTY****6.1 INTRODUCTION**

Post-operative total knee arthroplasty (TKA) follow up evaluations reveal that one third of participants appeared to be dissatisfied with their operation despite having excellent objective outcomes (Dickstein et al. 1998). A study conducted by Singh et al. (2008) concluded that physical health related quality of life deficits exist in veterans following TKA surgery in comparison to the age- and gender-matched general US population and with veteran controls and proposed that future studies are needed to determine the causes of these deficits as well as the interventions to improve these deficits. Post-operative TKA studies have suggested that the participants who have a discernible low mental health score prior to TKA surgery, are more likely to have a poorer outcome at one and two years post-operatively (Lingard et al. 2004). Thus, using health related quality of life (HRQoL) measurement tools, such as SF-36 Health Survey, the Knee Injury and Osteoarthritis Outcome Score (KOOS) and the Tegner activity scale, may be able to identify possible areas of concern, alleviate the problems and optimise patient physical and mental wellbeing.

The KOOS questionnaire is a valid, reliable, and responsive outcome measure in total joint replacements (Roos & Toksvig-Larsen 2003). It is a patient-reported outcome measurement instrument, developed to evaluate a patient's individual opinion about their knee and associated problems and therefore served as a good indicator of the participant's perception of their overall knee function. The SF-36 health survey is a validated self-report questionnaire that consists of 36 questions (Jenkinson et al. 1994). It is a widely used generic measure of health-related quality of life. It makes use of physical and mental health summary measures in order to investigate the relative burden of disease (Ware 2000) and was used to discriminate between the participant's perception of physical and mental QoL. The Tegner activity scale is widely used as a tool to assess knee function and activity levels following knee ligament injuries and was recently validated for use in participants post-TKA surgery (Swanenburg et al. 2014). The Tegner activity scale was used as an indication of the participant's perceived level of activity.

The purpose of this research study was to utilise these self-report questionnaires to determine if an eccentric cycling exercise intervention produces greater improvements in the perception of knee function, overall wellbeing and quality of life, and level of physical activity when compared to the concentric exercise intervention.

## **6.2 METHODOLOGY**

Each research participant was required to complete the physical ability scores, namely the Knee injury and Osteoarthritis Outcome Score (KOOS), the SF-36 Health Survey and the Tegner Activity Scale prior to and following their rehabilitation intervention. The preceding questionnaires were distributed during the familiarisation session for the isokinetic strength testing, whereby each participant filled out the necessary documentation. Once the participants had completed the required 80% of their rehabilitation intervention, they received the follow up questionnaires during their post-testing session, four to eight days following their final Grucox exercise session.

### **6.2.1 Knee Injury And Osteoarthritis Outcome Score (KOOS)**

The KOOS (Appendix D) as described in section 3.2.1.1, was used to assess knee function. The KOOS consists of five subscales, which include; pain, other symptoms, function in daily living (ADL), function in sport and recreation (Sport/Rec) and knee related quality of life (QoL). The week prior to questionnaire completion was taken into consideration when answering the questions.

### **6.2.2 SF- 36 Health Survey**

The SF-36 (Appendix E) as described in section 3.2.1.2, is a multi-purpose, short-form health survey. It yields an eight-scale profile of functional health and well-being

scores as well as psychometrically based physical and mental health summary measures and a preference-based health utility index.

### **6.2.3 The Tegner Activity Scale**

The Tegner Activity Scale (Appendix F) as described in section 3.2.1.3, is used as a measure of physical activity. The participants were required to select the number pertaining to the level of physical activity that best describes their current physical state.

### **6.2.4 Statistical Analysis**

Data were analysed as described in section 3.3.

## 6.3 RESULTS

### 6.3.1 Knee Injury And Osteoarthritis Outcome Score (KOOS)

There were no significant differences in the pre- to post-intervention change in the KOOS subscale percentage scores (pain,  $P= 0.301$ ; symptom,  $P= 0.724$ ; ADL,  $P= 0.783$ ; Sport/Rec,  $P= 0.651$  and QoL,  $P= 0.929$ ) between the ECC group and the CON group. There was a tendency towards a significant increase in the KOOS Sport/Rec subscale for both the ECC ( $p= 0.078$ ) and CON ( $P= 0.089$ ) intervention group from the pre to the post-intervention test. There were no further significant changes for the KOOS subscales as a result of the respective interventions in either the ECC group or the CON group from the pre to the post-intervention test (Table 6.1).

The effect size for the pre- to post-intervention change for the KOOS subscales (Pain,  $ES= 0.28$ ; Symptom,  $ES= 0.12$ ; ADL,  $ES= 0.10$ ; Sport/Rec,  $ES= 0.20$  and QoL,  $ES= 0.03$ ) were characterised as trivial to small differences between the ECC and CON groups. The effect size for the change in the ECC group for the KOOS Sport/Rec subscale ( $ES= 0.90$ ) was characterised as a moderate increase from the pre- to post-intervention test. The effect size for the change in the CON group for the KOOS Sport/Rec subscale ( $ES= 0.86$ ) was characterised as a moderate increase from the pre- to post-intervention test. The effect sizes for the change in the remaining KOOS subscales of the ECC and CON groups were characterised as trivial to small differences from the pre- to post-intervention test.

**Table 6.1: A comparison of the KOOS Subscale Scores between the eccentric (ECC) and concentric (CON) intervention group.**

Variable:	Intervention Group											
	ECC Group (n=9)					CON Group (n=9)					ECC vs. CON	
	Pre-Test	Post-Test	P <sup>1</sup>	ES <sup>1</sup>	Pre-Test	Post-Test	P <sup>2</sup>	ES <sup>2</sup>	P <sup>3</sup>	ES <sup>3</sup>		
Pain (%)	90.4 ± 9.1	82.5 ± 9.9	0.776	0.14	86.7 ± 13.4	76.2 ± 15.9	0.496	0.33	0.301	0.28		
Symptom (%)	82.5 ± 9.9	84.5 ± 9.8	0.674	0.20	76.2 ± 15.9	79.8 ± 14.1	0.620	0.24	0.724	0.12		
ADL (%)	89.1 ± 11.1	91.3 ± 8.2	0.626	0.24	81.9 ± 12.3	85.3 ± 11.0	0.541	0.29	0.783	0.10		
Sport/Rec (%)	41.7 ± 27.4	62.8 ± 19.4	0.078	<b>0.90</b>	34.3 ± 16.9	51.1 ± 21.9	0.089	<b>0.86</b>	0.651	0.20		
QoL (%)	60.4 ± 20.3	70.1 ± 18.4	0.303	0.50	59.0 ± 30.5	69.4 ± 23.9	0.432	0.36	0.929	0.03		

<sup>1</sup>: ECC Pre vs. ECC Post-Test; <sup>2</sup>: CON Pre vs. CON Post-Test; <sup>3</sup>: ECC vs. CON. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; P, P-value; ES, effect size; ADL, activities of daily living; Sport/Rec, sport and recreation; QoL, quality of life; %, percentage. Significant values are shown with bold typeset.

### **6.3.2 SF- 36 Health Survey**

There was a significant difference in the pre- to post-intervention change in the SF-36 emotional role functioning score between the ECC group and the CON group (ECC group +14.82%, CON group +49.03%,  $P= 0.044$ ). There were no further significant differences in the pre- to post-intervention change in the SF-36 subscale scores (vitality,  $P= 0.549$ ; physical functioning,  $P= 0.512$ ; bodily pain,  $P= 0.360$ ; general health,  $P= 0.856$ ; physical role functioning,  $P= 0.999$ ; social role functioning,  $P= 0.359$  and mental health,  $P= 0.903$ ) between the ECC group and the CON group. There was a significant increase in the SF-36 emotional role functioning subscale ( $P\leq 0.001$ ) and a tendency towards a significance increase in the bodily pain subscale ( $P= 0.085$ ) in the CON group from the pre to the post-intervention test. There were no further significant changes for the SF-36 subscales as a result of the respective interventions in either the ECC group and the CON group from the pre to the post- intervention test (Table 6.3).

The effect size for the pre- to post-intervention change for the SF-36 emotional role functioning score ( $ES= 0.93$ ) was characterised as a moderate difference between the ECC and CON groups. The effect size for the pre- to post-intervention change for the SF-36 subscales (vitality,  $ES= 0.30$ ; physical functioning,  $ES= 0.35$ ; bodily pain,  $ES= 0.38$ ; general health,  $ES= 0.04$ ; physical role functioning,  $ES= 0.00$ ; social role functioning,  $ES= 0.39$  and mental health,  $ES= 0.05$ ), were characterised as trivial to small differences between the ECC and CON groups.

The effect size for the change in the CON group for the SF-36 emotional role functioning score was characterised as a very large increase (ES= 2.69) from the pre- to post-intervention test. The effect size for the change in the CON group for the SF-36 vitality score (ES= 0.72) was characterised as a moderate increase from the pre- to post-intervention test.

The effect size for the change in the ECC group for the SF-36 physical functioning score (ES= 0.74), the SF-36 physical role functioning score (ES= 1.01) and the SF-36 emotional role functioning score (ES= 1.01) was characterised as a moderate increase from the pre- to post-intervention test. The effect sizes for the change for the remaining SF-36 subscales of the ECC and CON groups were characterised as trivial to small differences from the pre- to post-intervention test.

There was a significant difference between the ECC and CON pre-test score for the SF-36 bodily pain subscale (P= 0.031) and emotional role functioning subscale (P= 0.044), whereby the CON group showed a significantly lower pre-test score in comparison to the ECC group. There were no further significant differences between the ECC and CON intervention group's pre- test and post- test scores.

**Table 6.2: A comparison of the SF-36 Health Survey Subscale Scores between the eccentric (ECC) and concentric (CON) intervention group.**

	Intervention Group											
	ECC Group (n=9)						CON Group (n=9)					
	Pre-Test	Post-Test	P <sup>1</sup>	ES <sup>1</sup>	Pre-Test	Post-Test	P <sup>2</sup>	ES <sup>2</sup>	P <sup>3</sup>	ES <sup>3</sup>		
<b>SF-36 Subscales:</b>												
Vitality (%)	69.4 ± 19.6	75.6 ± 14.2	0.460	0.36	56.1 ± 20.4	68.3 ± 13.5	0.153	<b>0.72</b>	0.549	0.30		
Physical Functioning (%)	70.6 ± 22.6	82.8 ± 10.3	0.159	<b>0.74</b>	56.1 ± 24.1	60.0 ± 26.0	0.746	0.16	0.512	0.35		
Bodily Pain (%)	79.2 ± 17.7	88.7 ± 11.6	0.199	0.65	58.3 ± 19.8	75.2 ± 19.1	0.085	<b>0.87</b>	0.360	0.38		
General Health (%)	83.2 ± 10.1	82.7 ± 10.1	0.909	0.05	73.7 ± 16.8	73.8 ± 17.9	0.989	0.01	0.856	0.04		
Physical Role Functioning (%)	77.8 ± 44.1	100.0 ± 0.0	0.150	<b>1.01</b>	47.2 ± 45.8	69.4 ± 41.0	0.295	0.51	0.999	0.00		
Emotional Role Functioning (%)	85.2 ± 29.4	100.0 ± 0.0	0.150	<b>1.01</b>	51.0 ± 36.5	100.0 ± 0.0	<b>≤0.001</b>	<b>2.69</b>	<b>0.044</b>	0.94		
Social Role Functioning (%)	90.3 ± 19.5	85.2 ± 29.4	0.596	0.29	76.4 ± 21.1	88.9 ± 14.6	0.163	0.70	0.359	0.39		
Mental Health (%)	83.1 ± 12.6	85.8 ± 10.4	0.631	0.23	78.2 ± 9.8	81.3 ± 11.0	0.535	0.30	0.903	0.05		

<sup>1</sup>: ECC Pre vs. ECC Post-Test; <sup>2</sup>: CON Pre vs. CON Post-Test; <sup>3</sup>: ECC vs. CON. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; P, P-value; ES, effect size. Significant values are shown with bold typeset.

### **6.3.3 The Tegner Activity Scale**

There was tendency towards a significant difference in the pre- to post-intervention change in the Tegner activity scale between the ECC group and the CON group (ECC group +0.88, CON group +0.11,  $P= 0.094$ ). The Tegner activity scale of the ECC group increased significantly (Pre,  $2.67 \pm 0.95$ , Post;  $3.56 \pm 0.70$ ;  $P= 0.031$ ) following the eccentric rehabilitation intervention. There were no significant changes in the Tegner activity scale in the CON group (Table 6.2).

The effect size for the pre- to post-intervention change in the Tegner activity scale ( $ES= 1.10$ ) was characterised as a moderate to large difference between the ECC and CON groups. The effect size for the change in the Tegner activity scale of the ECC group was characterised as a moderate to large difference ( $ES= 1.16$ ), from the pre- to post-intervention test.

**Table 6.3: A comparison of the Tegner activity scale between the eccentric (ECC) and concentric (CON) intervention group.**

Variable:	Intervention Group									
	ECC Group (n=9)				CON Group (n=9)				ECC vs. CON	
	Pre-Test	Post-Test	P <sup>1</sup>	ES <sup>1</sup>	Pre-Test	Post-Test	P <sup>2</sup>	ES <sup>2</sup>	P <sup>3</sup>	ES <sup>3</sup>
Activity Level	2.7 ± 1.0	3.6 ± 0.5	<b>0.031</b>	<b>1.16</b>	3.0 ± 0.0	3.1 ± 0.8	0.675	0.28	0.094	<b>1.10</b>

<sup>1</sup>: ECC Pre vs. ECC Post-Test; <sup>2</sup>: CON Pre vs. CON Post-Test; <sup>3</sup>: ECC vs. CON; ES, ECC vs. CON. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; P, P-value; ES, effect size. Significant values are shown with bold typeset.

## 6.4 DISCUSSION

The primary objective of this study was to determine whether an eccentric or concentric cycling rehabilitation intervention produces greater improvements in knee function and perception of overall wellbeing and quality of life, as measured by validated self-report health questionnaires. These questionnaires included the Knee Injury and Osteoarthritis Outcome Score (KOOS), the Tegner Level of Activity Scale and the SF-36 Health Survey.

The main findings of this study show that although there was only a tendency for the eccentric (ECC) group to increase its level of activity as a result of the eccentric rehabilitation intervention, it resulted in a moderate to large increase in the Tegner Ability score when compared to the concentric rehabilitation intervention. Additionally, as a result of the eccentric rehabilitation intervention, there was a significant increase in the activity level from the pre- to post-intervention test of the ECC group. Correspondingly, the effect size calculations show a moderate to large increase in the Tegner activity scale of the ECC group from the pre- to post-intervention test. In addition to the Tegner activity scale results, there was a moderate increase in physical functioning of the ECC group, from the pre- to post-intervention test. These results suggest that the ECC group may show greater improvement in the reported level of physical ability following the rehabilitation intervention when compared to the CON group.

There was a significant difference in the pre- to post-intervention change in the SF-36 emotional role functioning score between the ECC and CON group, where there was a significant increase in the CON group from the pre- to post-intervention test. Correspondingly, the effect size calculations show a very large increase in the SF-36 emotional role functioning score in the CON group, whilst the ECC group showed a moderate increase in the SF-36 emotional role functioning score from the pre- to post-intervention test. It is however important to note that the CON group had a significantly lower SF-36 emotional role functioning score prior to the intervention, in comparison to the ECC group. Additionally, each group achieved a maximum emotional role functioning score following the respective interventions. Further, the CON group shows a moderate increase in the SF-36 bodily pain and vitality score from the pre- to post-intervention test. There were no further significant differences in the SF-36 subscale scores between the ECC group and the CON group. These results imply that the CON group experience greater improvements in their perception of overall health and emotional functioning following the rehabilitation intervention, however there were no significant differences between the ECC and CON groups post- intervention scores and both groups reported equivalent perceptions of their functional health and well-being following the rehabilitation interventions.

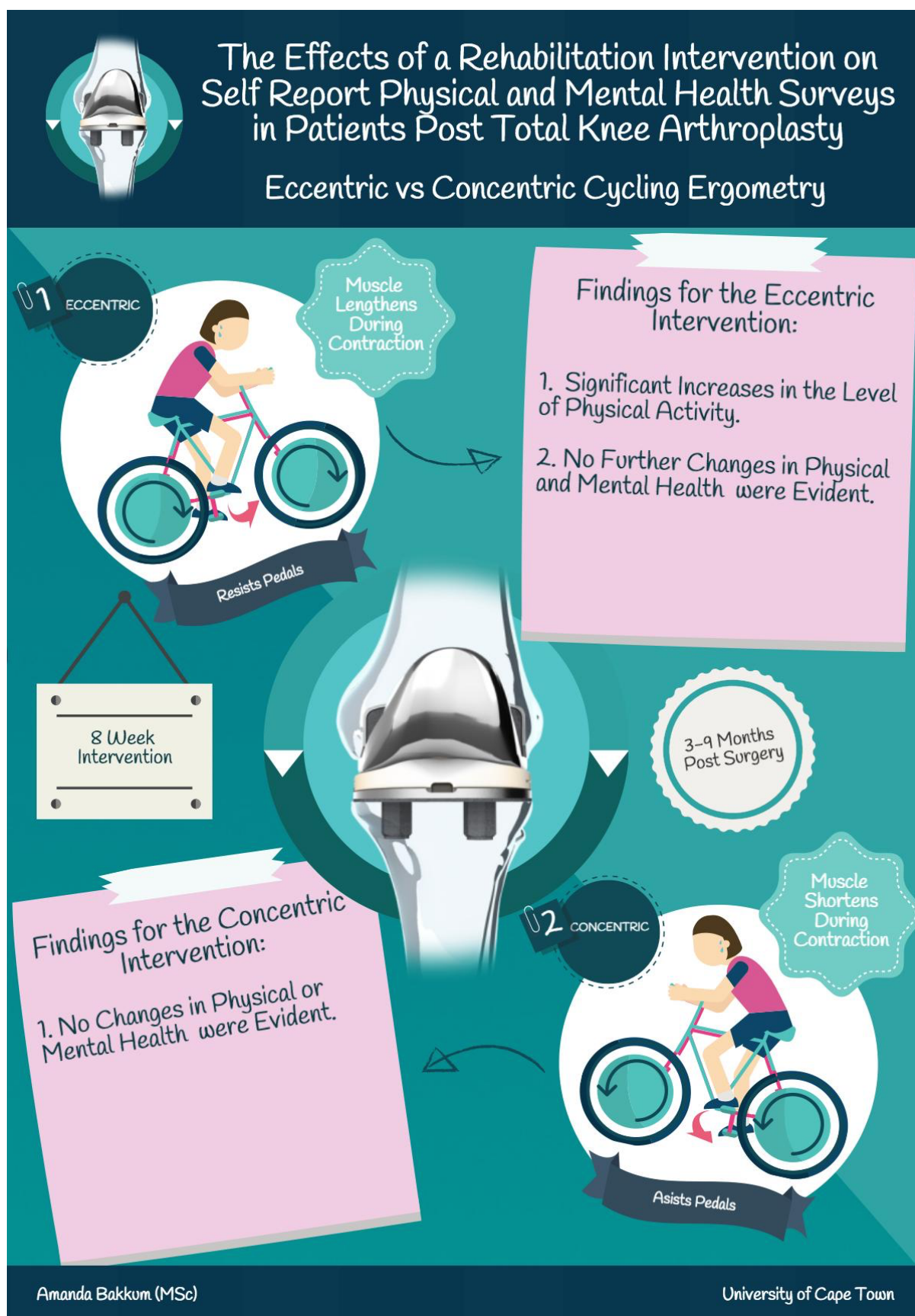
There were no statistically significant differences in knee function as measured by the KOOS, between the ECC and CON groups. Although there was a tendency for both the ECC and CON intervention group to increase their KOOS sport and recreation (Sport/Rec) subscale scores as a result of the interventions, there was a moderate increase in the KOOS Sport/Rec score in both groups from the pre- to

post-intervention test. The KOOS score is in effect an extension of the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and was developed due to the propensity of certain participants eligible for TKA surgery having higher expectations of more demanding physical functions than those required for everyday living (Roos & Toksvig-Larsen 2003). Whilst this was the case for a number of participants, it was not accurate for all the participants in this study. Therefore, the results may be skewed in that the measuring instrument employed did not accurately depict or encompass each participant's expectations regarding their desired post-operative level of functioning.

The limitations of this study include the relatively high standard deviations that may be due to the heterogeneity of the patient population. These high standard deviations could have played a role in the few statistically significant differences found in this study. It is suggested that future studies should investigate larger populations or investigate a more homogenous population of participants. Another limitation to this study was that, despite the groups being equivalent in all outcomes of the preceding studies, the groups were not equivalent in terms of their SF-36 bodily pain and emotional role functioning subscale scores prior to the interventions. The reason for this is unknown and appears purely coincidental. Consequently, it may influence how the results are perceived and interpreted, as it may appear that one group has improved to a greater degree. However, as the questionnaire has a maximum score of 100%, one group may appear to have shown greater improvement over time, yet both groups will have the same final score of 100%. It is suggested that future research studies utilise these questionnaires as possible selection criteria or alternatively, a means to group participants based on their initial scores.

Additionally, a study conducted by Stevens-Lapsley et al. (2011) showed that patient's self-reported answers on the KOOS questionnaire did not accurately reflect the extent to which the performance deficits were still present following TKA surgery. The results of this study highlighted the importance of including physical performance measures and functional testing when managing and tracking recovery following TKA surgery as opposed to relying solely on self-reported measures and perception.

Overall, the results suggest that the eccentric rehabilitation intervention may elicit superior end results related to the physical functioning and activity levels, however both intervention groups show similar patterns of change across the intervention period (Figure 6.1). Further research is required to investigate the effects of eccentric and concentric ergometry on the perception of overall wellbeing, quality of life, and level of physical activity in participants post total knee arthroplasty.



**Figure 6.1.** An infographic summarising the conclusions of Study 3.

**CHAPTER 7****STUDY 4: THE SIT-TO-STAND TRANSFER IN PATIENTS POST TOTAL KNEE  
ARTHROPLASTY AFTER EITHER AN ECCENTRIC OR CONCENTRIC  
REHABILITATION INTERVENTION: AN EXPLORATORY STUDY****7.1 INTRODUCTION**

The extent of the functional recovery in participants post total knee arthroplasty (TKA) is often assessed using self-report questionnaires and health surveys. Whilst beneficial, these self-report measures are limited in the amount of information provided as they assess the patient's perspective on their physical ability to perform a task and are thus limited in terms of objectivity, as discussed in chapter 6. Therefore, it is important to make use of performance-based tests in order to assess a patient's physical ability to perform a task.

The sit-to-stand (STS) transfer is a common activity performed by most individuals throughout their daily activities. The transfer from a seated position to a standing position is a fundamental prerequisite for numerous activities required in daily living and is one of the most mechanically demanding tasks that individuals perform on a day-to-day basis (Riley et al. 1991). This motion requires the transition from a comparatively large, steady base of support utilised during sitting, to a considerably smaller base of support utilised in a standing position. The STS transfer has been used as an functional outcome assessment in participants post-TKA (Mizner & Snyder-Mackler 2005; Farquhar et al. 2009) as well as numerous other pathologies

(Busse et al. 2006; Hoglund et al. 2009; Huffman et al. 2015; Lee et al. 2014) However, to our knowledge there is no research describing the effects of a rehabilitation intervention on the STS transfer in participants post-TKA.

Previous studies utilising the STS transfer as a measure of functional performance have investigated both kinematic variables, namely; flexion and extension angles and moments of the hip and/or knee joint (Hogland et al. 2009; Wang et al. 2008), abduction and adduction angles and moments of the hip joint (Hogland et al. 2009; Huffman et al. 2015), as well as kinetic variables such as vertical and anterior-posterior ground reaction forces (Mizner et al 2005; Hogland et al. 2009; Wang et al. 2008). As the participants of this study were positioned at 90° of knee flexion with their feet separated onto two separate force plates at the beginning of the STS transfer, hip and knee joint flexion and extension angles and moments were not considered during data analysis. However, to our knowledge, there are no studies that have described and compared the knee valgus-varus (Val/Var) angles in participant's post-TKA surgery during the STS transfer, thus these variables were included in the data analysis of this study. The knee valgus angle represents the inward bend of the knee whilst the knee varus angle corresponds to the outward bend of the knee (Plug-In-Gait Manual; Gait 2008). The Val/Var angles describe the medial and lateral displacement of the knee respectively, and may serve as an indication of knee stability during the STS transfer in participant's post-TKA surgery. The research studies investigating the STS as a functional outcome are described in greater detail to follow.

A clinical study conducted by Mizner and Snyder-Mackler et al. (2005) utilised the STS transfer as a tool to describe the effects of TKA surgery. This study investigated the effect of quadriceps weakness on altered loading patterns during walking and the STS transfer following a TKA surgery. The results showed that during the STS transfer, quadriceps muscle activity and the extension moments at the knee and hip in the involved limb were less than those of the uninvolved limb. This study highlighted that the TKA participants continued to shift their weight away from the operated limb. It was concluded that quadriceps weakness in participants with TKA has a substantial impact on the movement patterns and performance of the knee during functionally important tasks (Mizner & Snyder-Mackler 2005).

A further study showed that participants with TKA showed improvements in symmetry of motion, strength, and functional performance from three months to one year following TKA (Farquhar et al. 2008). However, when compared with control participants, the TKA participants relied on increased hip flexion and a larger hip extensor moment to perform the STS task. They suggested that participants adopted a strategy to avoid the use of the quadriceps femoris muscle by increasing their hip extensor moment. This strategy persisted as quadriceps femoris muscle strength improved. The study concluded that the altered muscle activity pattern might be a learned movement pattern that may not resolve without retraining.

As mentioned previously, there are studies that have utilised the STS transfer as a measure of functional ability in participants with pathologies other than TKA. A study conducted by Hogland et al. (2009) aimed to examine the hip and knee kinetics during the sit-to-stand (STS) transfer in persons with bilateral, symptomatic,

radiographic patellofemoral osteoarthritis (PFOA) compared to asymptomatic persons free from radiographic PFOA (control participants). Anthropomorphic, strength and joint kinetic data were collected and the STS data was examined at four epochs, including, maximum (MAX) and minimum (MIN) values, at the “seat-off” (SO) point and at the end (END) of the STS. The results of this study showed that the PFOA group was associated with increased hip and knee internal moments during the STS and that hip extension (EXT), abduction (ABD), and external rotation (ER) moments were increased at MAX, SO, and END. Additionally, knee EXT and adduction (ADD) moments were increased at SO. There were significant between-limb differences at the hip, whereby the uninvolved limb had increased hip abduction and external rotation moments at MAX and end events. The study concluded that the increased hip ABD and ER moments in the PFOA group might be a compensatory technique as an attempt to prevent the involved limb from collapsing medially.

Finally, Huffman et al. (2015) analysed and compared the sit-to-stand transfer outcomes of individuals with a high BMI and persons with normal BMI in order to identify and describe possible factors related to total hip arthroplasty dislocation, which has been associated with obese individuals (Huffman et al. 2015). The results of the study showed that peak hip abduction angles and moments were significantly greater in the high BMI group and suggest that further research is required to determine if the increase in hip abduction angle and moment observed during STS is a contributing factor for complications following THA in obese participants (Huffman et al. 2015). These results may be of interest as given the nature of the TKA patient population, the propensity for being inactive and overweight is high and thus may impact on the participant’s ability to perform the STS transfer.

From the abovementioned studies it is evident that STS transfer has been utilised as a measure of functional performance in a variety of pathologies, including TKA, however the effects of a rehabilitation intervention on the STS transfer had not been investigated in participant's post-TKA. Thus, the primary purpose of this study was to describe and compare the STS motion using kinematic and kinetic data of participant's three to nine months' post-TKA surgery randomised into an eccentric or concentric rehabilitation intervention. Specifically, we would like to describe the vertical and anterior-posterior ground reaction forces, hip abduction-adduction and knee valgus-varus joint angles, as well as the muscle activity in the vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) of both the involved and uninvolved limbs.

## 7.2 METHODOLOGY

### 7.2.1 The Sit-To-Stand Transfer

Kinematic and kinetic data was recorded using an AMTI® force plate and an eight-camera Vicon motion capture system (Oxford Metric Vicon) as described in section 3.2.5. The Vicon motion capture system was used to analyse knee and hip joint angles while standing up from a seated position (sit-to-stand transfer). Retro reflective anatomical markers were placed bilaterally according to the Plug-in Gait lower body modelling marker sets designed for the Newington-Helen Hayes model on which Plug-in Gait is based. The marker set included markers for the pelvis and the lower limbs as described in detail in chapter 3.2.5.

The participants were asked to rise from a seated position (STS transfer) as described in section 3.2.5.1. The participants were positioned on a chair at approximately 90° (degrees) of knee flexion, with their feet approximately shoulder width apart, with each foot placed on a separate force plate. The participants were asked to stand up from the chair at a self-selected pace (Figure 3.5). The STS data was divided into two phases, using 45° of knee flexion as a marker. Phase one denotes the STS movement that occurs up until 45° of knee flexion, whilst phase two represents the STS movement that occurs after 45° of knee flexion. The peak values across two successful trials were used for analysis.

The STS kinetics data included the peak values of anterior-posterior ground reaction force (AP-GRF) and vertical ground reaction force (V-GRF). All force data was normalised to body weight and is represented as newton-meters per kilogram (N.m/kg). The kinematic variables considered for analysis in this study include hip and knee joint angles. The hip abduction-adduction joint angle and knee valgus-varus joint angles are under investigation. The guidelines for interpretation of these parameters are described below.

### **7.2.1.1 Vertical Ground Reaction Force**

The force with the largest magnitude that the ground imparts on your body is the vertical ground reaction force (V-GRF). The V-GRF represents the acceleration of the body's centre of mass in the vertical direction during the STS transfer (Figure 3.6).

### **7.2.1.2 Anterior-Posterior Ground Reaction Force**

The anterior-posterior ground reaction force (AP-GRF) represents the horizontal force exerted on the force plate by the foot (Figure 3.6). A negative number corresponds to a backwards or posterior force exerted by the foot on the force plate. Conversely, a positive value represents a forward or anterior force exerted by the foot on the force plate.

### **7.2.1.3 Knee Valgus-Varus Angle**

A positive number corresponds to a varus or outward bend of the knee. Conversely, a negative angle corresponds to a valgus or inward bend of the knee (Figure 3.4) (Plug-In-Gait Manual; Gait 2008).

### **7.2.1.4 Hip Abduction-Adduction Angle**

A positive number corresponds to an adducted or inwardly moving leg (Figure 3.4) (Plug-In-Gait Manual; Gait 2008). Alternatively, a negative angle represents abduction whereby the leg moves outwardly.

## **7.2.2 Electromyography**

EMG data was recorded throughout the STS trials and normalised to the peak amplitude of the second contraction in the isokinetic testing trial, which is described in detail in section 3.2.2. The EMG signal was taken from the following muscles: vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) of both the involved and uninvolved limbs. The electrodes were placed on the belly of the muscle in accordance with the SENIAM recommendations as previously described in section 3.2.2.

The vastus medialis (VM) is located on the medial border of the thigh and plays an active role in knee extension (Section 5.2.2.1). The vastus lateralis (VL) muscle is located on the lateral border of the anterior compartment of the thigh and is actively involved in knee extension (Section 5.2.2.2). The biceps femoris (BF) muscle resides in the posterior compartment of the thigh. This muscle forms part of the hamstring muscle group and plays a role in hip extension (Section 5.2.2.3).

### **7.2.3 Statistical Analysis**

Data were analysed as described in section 3.3.

## 7.3 RESULTS

### 7.3.1 Ground Reaction Forces

#### 7.3.1.1 Vertical Ground Reaction Force

There were no significant differences in the pre- to post-intervention change in the peak vertical ground reaction force (V-GRF) between the ECC group and the CON group for their involved limb (ECC group  $-0.00$  N.m/kg, CON group  $+0.03$  N.m/kg,  $P=0.239$ ) and uninvolved limb (ECC group  $-0.01$  N.m/kg, CON group  $-0.02$  N.m/kg,  $P=0.682$ ) (Figure 7.1).

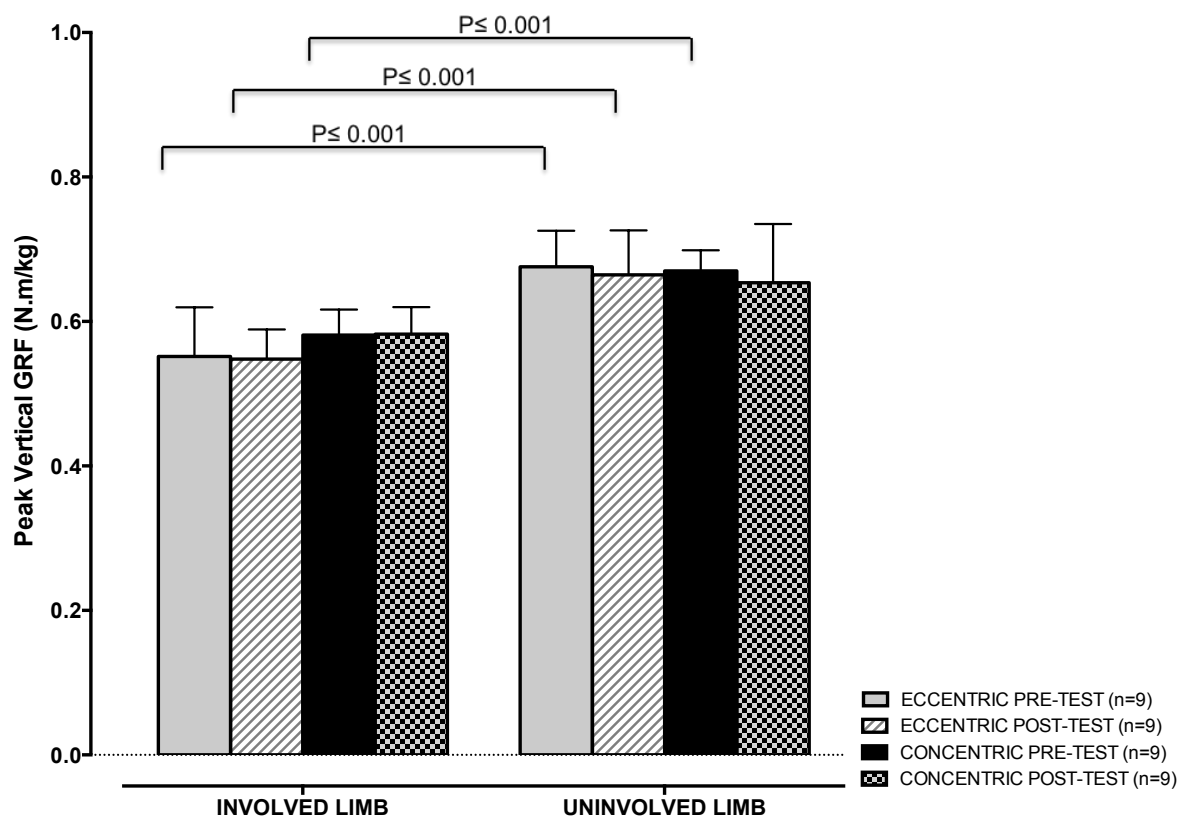
There were no significant changes in peak V-GRF as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P=0.894$ , CON group  $P=0.184$ ) and the uninvolved limb (ECC group  $P=0.683$ , CON group  $P=0.513$ ) from the pre to the post-intervention test.

There was a significant difference in peak V-GRF between the involved and uninvolved limbs of the ECC group before (Involved,  $0.56 \pm 0.07$  N.m/kg; Uninvolved,  $0.68 \pm 0.05$  N.m/kg;  $P \leq 0.001$ ) and after (Involved,  $0.55 \pm 0.04$  N.m/kg; Uninvolved,  $0.67 \pm 0.06$  N.m/kg;  $P \leq 0.001$ ) the rehabilitation intervention. There was a significant difference in peak V-GRF between the involved and uninvolved limbs of the CON group before the rehabilitation intervention (Involved,  $0.56 \pm 0.06$  N.m/kg; Uninvolved,  $0.67 \pm 0.03$  N.m/kg;  $P \leq 0.001$ ) and a tendency towards significance after

(Involved,  $0.59 \pm 0.04$  N.m/kg; Uninvolved,  $0.65 \pm 0.08$  N.m/kg;  $P= 0.093$ ) the rehabilitation intervention.

The effect size for the pre- to post-intervention change in peak V-GRF was characterised as a small to moderate difference in the involved limb (ES= 0.63) and a small difference in the uninvolved limb (ES= 0.42) between the ECC and CON groups. The effect size for the change in the peak V-GRF of the ECC group was characterised as a trivial to small difference for the involved limb (ES= 0.07) and the uninvolved limb (ES= 0.20), from the pre- to post-intervention test. The effect size for the change in the peak V-GRF of the CON group was characterised as a small to moderate difference for the involved limb (ES= 0.66) and a small difference for the uninvolved limb (ES= 0.40), from the pre- to post-intervention test.

The effect size for the difference in the peak V-GRF between the involved and uninvolved limbs of the ECC group was characterised as a very large difference before (ES= 2.10) and after (ES= 2.27) the rehabilitation intervention. The effect size for the difference in the peak V-GRF between the involved and uninvolved limbs of the CON group was characterised as a very large difference before (ES= 2.64) and a moderate difference after (ES= 0.92) the rehabilitation intervention.



**Figure 7.1.** A comparison of the peak vertical ground reaction force between the ECC and CON intervention groups during the Sit-to-stand transfer. Abbreviations: eccentric intervention group; CON, concentric intervention group; ECC, n, number of participants; GRF, ground reaction force; N.m/kg, Newton meters per kilogram.

### 7.3.1.2 Anterior-Posterior Ground Reaction Force

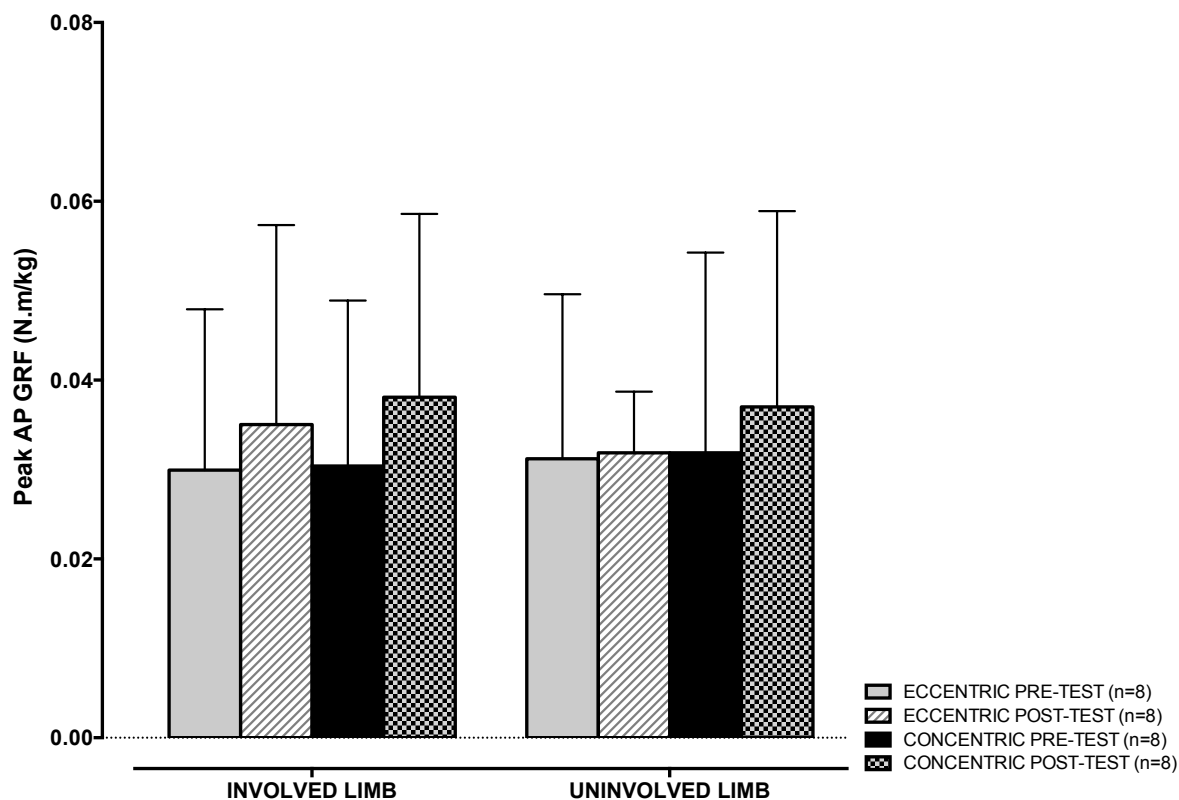
There were no significant differences in the pre- to post-intervention change in the peak anterior-posterior ground reaction force (AP-GRF) between the ECC group and the CON group for their involved limb (ECC group +0.01 N.m/kg, CON group +0.01 N.m/kg,  $P= 0.677$ ) and uninvolved limb (ECC group +0.00 N.m/kg, CON group +0.01 N.m/kg,  $P= 0.656$ ) (Figure 7.2).

There were no significant changes in peak AP-GRF as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.323$ ; CON group  $P= 0.416$ ) and the uninvolved limb (ECC group  $P= 0.989$ ; CON group  $P= 0.630$ ) from the pre to the post-intervention test.

There were no significant differences in peak AP-GRF between the involved and uninvolved limbs of the ECC group before (Involved,  $0.03 \pm 0.02$  N.m/kg; Uninvolved,  $0.03 \pm 0.02$  N.m/kg;  $P= 0.827$ ) and after (Involved,  $0.04 \pm 0.03$  N.m/kg; Uninvolved,  $0.03 \pm 0.01$  N.m/kg;  $P= 0.371$ ) the rehabilitation intervention. There were no significant differences in peak AP-GRF between the involved and uninvolved limbs of the CON group before the rehabilitation intervention (Involved,  $0.03 \pm 0.02$  N.m/kg; Uninvolved,  $0.03 \pm 0.02$  N.m/kg;  $P= 0.881$ ) and after (Involved,  $0.04 \pm 0.02$  N.m/kg; Uninvolved,  $0.04 \pm 0.02$  N.m/kg;  $P= 0.915$ ) the rehabilitation intervention.

The effect size for the pre- to post-intervention change in peak AP-GRF of the involved limb (ES= 0.19) and uninvolved limb (ES= 0.23) was characterised as a trivial to small difference between the ECC and CON groups. The effect size for the change in the peak AP-GRF of the ECC group was characterised as a trivial to small difference for the involved limb (ES= 0.49) and the uninvolved limb (ES= 0.01), from the pre- to post-intervention test. The effect size for the change in the peak AP-GRF of the CON group was characterised as a trivial to small difference for the involved limb (ES= 0.39) and the uninvolved limb (ES= 0.23), from the pre- to post-intervention test.

The effect size for the difference in the peak AP-GRF between the involved and uninvolved limbs of the ECC group was characterised as a trivial difference before (ES= 0.07) and as a small to moderate difference after (ES= 0.54) the rehabilitation intervention. The effect size for the difference in the peak AP-GRF between the involved and uninvolved limbs of the CON group was characterised as a trivial difference before (ES= 0.05) and after (ES= 0.07) the rehabilitation intervention.



**Figure 7.2.** A comparison of the peak anterior-posterior ground reaction force between the ECC and CON intervention groups during the Sit-to-stand transfer. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; GRF, ground reaction force; N.m/kg, Newton meters per kilogram.

### **7.3.2 Joint Kinematics**

#### **7.3.2.1 Peak Knee Valgus-Varus Angles**

There were no significant differences in the pre- to post-intervention change in the peak knee valgus-varus (Val/Var) angle between the ECC group and the CON group for their involved limb (ECC group  $-4.87^\circ$ , CON group  $-6.24^\circ$ ,  $P= 0.771$ ) and the uninvolved limb (ECC group  $+0.82^\circ$ , CON group  $-0.94^\circ$ ,  $P= 0.788$ ) during phase one of the STS transfer. There were no significant differences in the pre- to post-intervention change in the peak knee Val/Var angle between the ECC group and the CON group for their involved limb (ECC group  $+5.61^\circ$ , CON group  $-8.16^\circ$ ,  $P= 0.199$ ) and the uninvolved limb (ECC group  $-3.28^\circ$ , CON group  $-0.53^\circ$ ,  $P= 0.782$ ) during phase two of the STS transfer (Figure 7.3).

There were no significant changes in the peak knee Val/Var angle as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.268$ ; CON group  $P= 0.216$ ) and the uninvolved limb (ECC group  $P= 0.870$ ; CON group  $P= 0.858$ ) from the pre to the post-intervention test during phase one of the STS transfer. There were no significant changes in peak knee Val/Var angle as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.611$ ; CON group  $P= 0.573$ ) and the uninvolved limb (ECC group  $P= 0.749$ ; CON group  $P= 0.945$ ) from the pre to the post-intervention test during phase two of the STS transfer.

There were no significant differences in peak knee Val/Var angle, during phase one of the STS transfer, between the involved and uninvolved limbs of the ECC group before (Involved,  $2.12 \pm 11.07^\circ$ ; Uninvolved,  $2.39 \pm 10.94^\circ$ ;  $P= 0.960$ ) and after (Involved,  $-2.75 \pm 4.55^\circ$ ; Uninvolved,  $3.22 \pm 8.74^\circ$ ;  $P= 0.109$ ) the rehabilitation intervention. There were no significant differences in peak knee Val/Var angle, during phase two of the STS transfer, between the involved and uninvolved limbs of the ECC group before (Involved,  $1.56 \pm 22.48^\circ$ ; Uninvolved,  $12.35 \pm 21.91^\circ$ ;  $P= 0.347$ ) and after (Involved,  $7.17 \pm 20.58^\circ$ ; Uninvolved,  $9.07 \pm 18.21^\circ$ ;  $P= 0.847$ ) the rehabilitation intervention.

There were no significant differences in peak knee Val/Var angle, during phase one of the STS transfer, between the involved and uninvolved limbs of the CON group before the rehabilitation intervention (Involved,  $3.15 \pm 11.74^\circ$ ; Uninvolved,  $2.17 \pm 12.23^\circ$ ;  $P= 0.881$ ) and after (Involved,  $-3.09 \pm 4.68^\circ$ ; Uninvolved,  $1.23 \pm 6.14^\circ$ ;  $P= 0.165$ ) the rehabilitation intervention. There were no significant differences in peak knee Val/Var angle, during phase two of the STS transfer, between the involved and uninvolved limbs of the CON group before (Involved,  $13.59 \pm 31.52^\circ$ ; Uninvolved,  $16.57 \pm 15.31^\circ$ ;  $P= 0.813$ ) and after (Involved,  $5.43 \pm 24.69^\circ$ ; Uninvolved,  $16.04 \pm 14.77^\circ$ ;  $P= 0.315$ ) the rehabilitation intervention.

The effect size for the pre- to post-intervention change in the peak knee Val/Var angle of the involved limb ( $ES= 0.12$ ) and the uninvolved limb ( $ES= 0.14$ ), during phase one of the STS transfer, was characterised as a trivial to small difference between the ECC and CON groups. The effect size for the pre- to post-intervention change in the peak knee Val/Var angle of the involved limb ( $ES= 0.44$ ) and the

uninvolved limb (ES= 0.18), during phase two of the STS transfer, was characterised as a trivial to small difference between the ECC and CON groups.

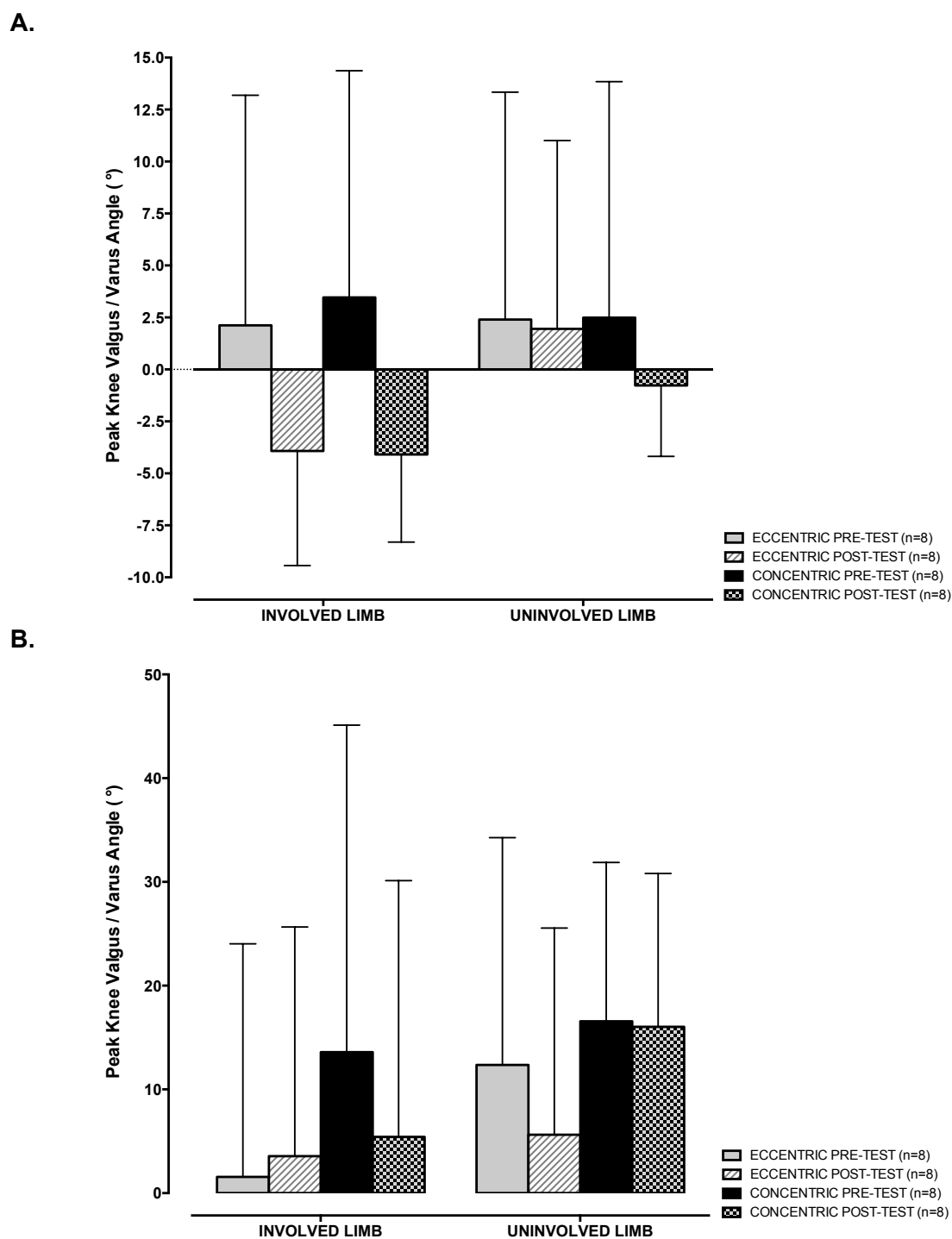
The effect size for the change in the peak knee Val/Var angle of the ECC group was characterised as a small to moderate difference for the involved limb (ES= 0.62), and a trivial difference for the uninvolved limb (ES= 0.08) from the pre- to post-intervention test during phase one of the STS transfer. The effect size for the change in the peak knee Val/Var angle of the CON group was characterised as a moderate difference for the involved limb (ES= 0.76), and a trivial to small difference for the uninvolved limb (ES= 0.10) from the pre- to post-intervention test during phase one of the STS transfer.

The effect size for the change in the peak knee Val/Var angle of the ECC group was characterised as a trivial to small difference for the involved limb (ES= 0.26), and the uninvolved limb (ES= 0.16) from the pre- to post-intervention test during phase two of the STS transfer. The effect size for the change in the peak knee Val/Var angle of the CON group was characterised as a trivial to small difference for the involved limb (ES= 0.29), and the uninvolved limb (ES= 0.04) from the pre- to post-intervention test during phase two of the STS transfer.

The effect size for the difference in the peak knee Val/Var angle, during phase one of the STS transfer, between the involved and uninvolved limbs of the ECC group was characterised as a trivial difference before (ES= 0.03) and as a moderate difference after (ES= 0.80) the rehabilitation intervention. The effect size for the difference in the peak knee Val/Var angle, during phase two of the STS transfer, between the

involved and uninvolved limbs of the ECC group was characterised as a small difference before (ES= 0.49) and a trivial difference after (ES= 0.10) the rehabilitation intervention.

The effect size for the difference in the peak knee Val/Var angle, during phase one of the STS transfer, between the involved and uninvolved limbs of the CON group was characterised as a trivial difference before (ES= 0.08) and as a moderate difference after (ES= 0.90) the rehabilitation intervention. The effect size for the difference in the peak knee Val/Var angle, during phase two of the STS transfer, between the involved and uninvolved limbs of the CON group was characterised as a trivial to small difference before (ES= 0.13) and a small to moderate difference after (ES= 0.54) the rehabilitation intervention.



**Figure 7.3. A)** A comparison of the peak knee valgus- varus angle between the ECC and CON intervention groups during phase one of the STS transfer. **B)** A comparison of the peak knee valgus- varus angle between the ECC and CON intervention groups during phase two of the STS transfer. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; °, degrees.

### 7.3.2.2 Peak Hip Abduction-Adduction Angles

Although not statistically significant, there was a tendency towards a statistically significant difference in the pre- to post-intervention change in the peak hip abduction-adduction (Abd/Add) angle between the ECC group and the CON group for their involved limb (ECC group  $-2.69^\circ$ , CON group  $+2.67^\circ$ ,  $P= 0.083$ ) and no significant difference in the uninvolved limb (ECC group  $-1.85^\circ$ , CON group  $-2.76^\circ$ ,  $P= 0.811$ ) during phase one of the STS transfer. There were no significant differences in the pre- to post-intervention change in the peak hip abduction-adduction (Abd/Add) angle between the ECC group and the CON group for their involved limb (ECC group  $-3.84^\circ$ , CON group  $-2.04^\circ$ ,  $P= 0.618$ ) and the uninvolved limb (ECC group  $-2.54^\circ$ , CON group  $+0.64^\circ$ ,  $P= 0.438$ ) during phase two of the STS transfer (Figure 7.4).

There were no significant changes in the peak hip Abd/Add angle as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.320$ ; CON group  $P= 0.355$ ) and the uninvolved limb (ECC group  $P= 0.547$ ; CON group  $P= 0.389$ ) from the pre to the post-intervention test during phase one of the STS transfer. There were no significant changes in the peak hip Abd/Add angle as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.223$ ; CON group  $P= 0.453$ ) and the uninvolved limb (ECC group  $P= 0.563$ ; CON group  $P= 0.891$ ) from the pre to the post-intervention test during phase two of the STS transfer.

There were no significant differences in peak hip Abd/Add angle, during phase one of the STS transfer, between the involved and uninvolved limbs of the ECC group before the rehabilitation intervention (Involved,  $4.39 \pm 5.53^\circ$ ; Uninvolved,  $0.64 \pm 5.41^\circ$ ;  $P= 0.191$ ) and after (Involved,  $6.59 \pm 3.28^\circ$ ; Uninvolved,  $3.19 \pm 6.47^\circ$ ;  $P= 0.201$ ) the rehabilitation intervention. There were no significant differences in peak hip Abd/Add angle, during phase two of the STS transfer, between the involved and uninvolved limbs of the ECC group before (Involved,  $4.21 \pm 7.40^\circ$ ; Uninvolved,  $2.16 \pm 8.32^\circ$ ;  $P= 0.609$ ) and after (Involved,  $8.00 \pm 3.97^\circ$ ; Uninvolved,  $5.58 \pm 8.73^\circ$ ;  $P= 0.460$ ) the rehabilitation intervention.

There were no significant differences in peak hip Abd/Add angle, during phase one of the STS transfer, between the involved and uninvolved limbs of the CON group before (Involved,  $-5.51 \pm 6.06^\circ$ ; Uninvolved,  $-2.74 \pm 5.53^\circ$ ;  $P= 0.356$ ) and after (Involved,  $-2.84 \pm 5.05^\circ$ ; Uninvolved,  $-5.49 \pm 6.82^\circ$ ;  $P= 0.391$ ) the rehabilitation intervention. There were no significant differences in peak hip Abd/Add angle, during phase two of the STS transfer, between the involved and uninvolved limbs of the CON group before (Involved,  $-6.73 \pm 4.13^\circ$ ; Uninvolved,  $-7.20 \pm 9.34^\circ$ ;  $P= 0.899$ ) and after (Involved,  $-8.77 \pm 6.22^\circ$ ; Uninvolved,  $-6.56 \pm 7.78^\circ$ ;  $P= 0.551$ ) the rehabilitation intervention.

The effect size for the pre- to post-intervention change in the peak hip Abd/Add angle of the involved limb ( $ES= 0.88$ ), during phase one of the STS transfer, was characterised as a moderate difference between the ECC and CON groups. The effect size for the pre- to post-intervention change in the peak hip Abd/Add angle,

during phase one of the STS transfer, was characterised as a trivial to small difference for the uninvolved limb (ES= 0.16), between the ECC and CON groups.

The effect size for the pre- to post-intervention change in the peak hip Abd/Add angle of the uninvolved limb (ES= 0.44), during phase two of the STS transfer, was characterised as a small to moderate difference between the ECC and CON groups.

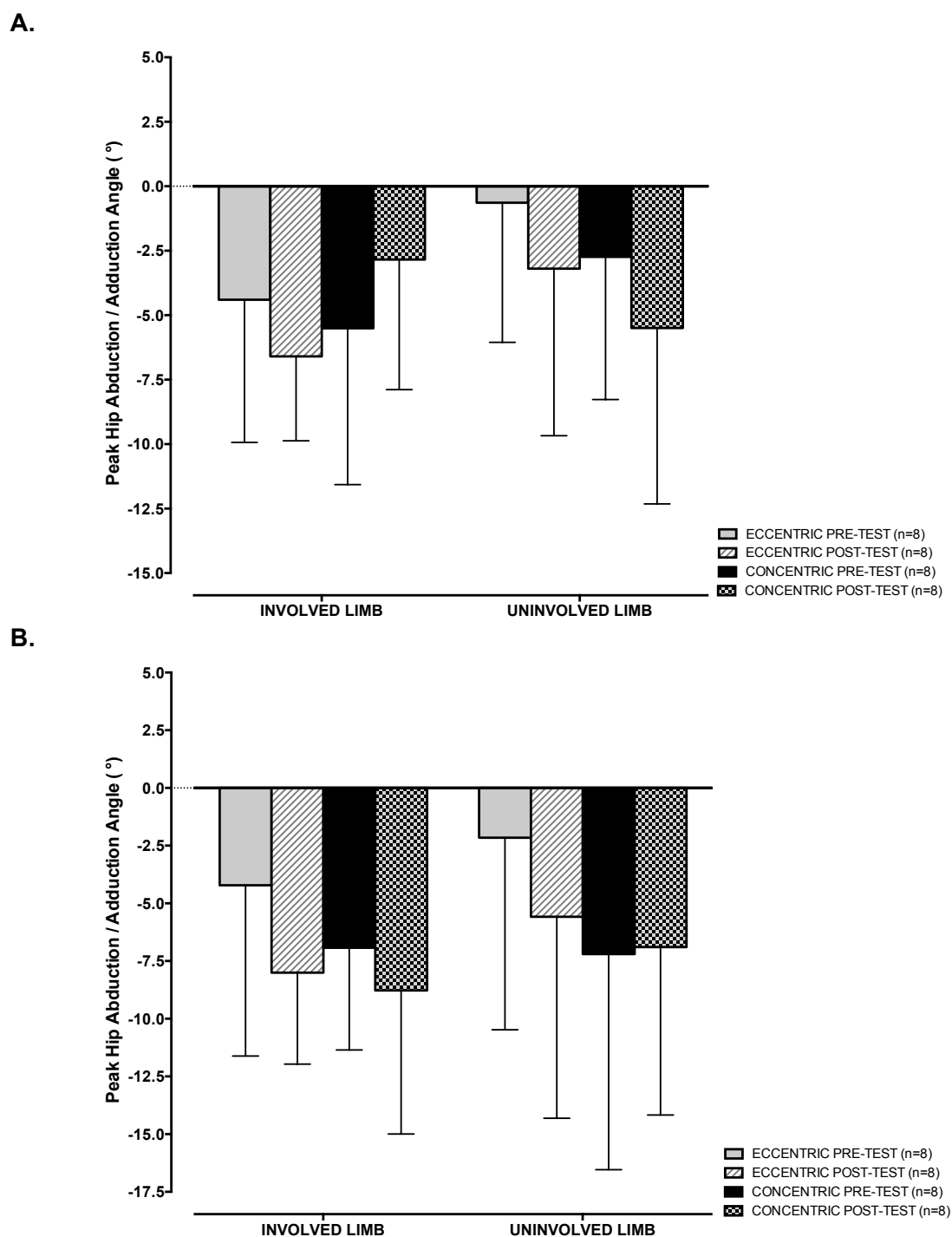
The effect size for the pre- to post-intervention change in the peak hip Abd/Add angle, during phase two of the STS transfer, was characterised as a small difference for the involved limb (ES= 0.34), between the ECC and CON groups.

The effect size for the change in the peak hip Abd/Add angle of the ECC group was characterised as a small difference for the involved limb (ES= 0.57), and the uninvolved limb (ES= 0.31) from the pre- to post-intervention test during phase one of the STS transfer. The effect size for the change in the peak hip Abd/Add angle of the CON group was characterised as a small difference for the involved limb (ES= 0.48), and the uninvolved limb (ES= 0.45) from the pre- to post-intervention test during phase one of the STS transfer.

The effect size for the change in the peak hip Abd/Add angle of the ECC group was characterised as a small to moderate difference for the involved limb (ES= 0.66), and a small difference for the uninvolved limb (ES= 0.30) from the pre- to post-intervention test during phase two of the STS transfer. The effect size for the change in the peak hip Abd/Add angle of the CON group was characterised as a trivial to small difference for the involved limb (ES= 0.39), and the uninvolved limb (ES= 0.07) from the pre- to post-intervention test during phase two of the STS transfer.

The effect size for the difference in the peak hip Abd/Add angle, during phase one of the STS transfer, between the involved and uninvolved limbs of the ECC group was characterised as a small to moderate difference before (ES= 0.62) and as a moderate difference after (ES= 0.88) the rehabilitation intervention. The effect size for the difference in the peak hip Abd/Add angle, during phase two of the STS transfer, between the involved and uninvolved limbs of the ECC group was characterised as a trivial to small difference before (ES= 0.26) and a small difference after (ES= 0.51) the rehabilitation intervention.

The effect size for the difference in the peak hip Abd/Add angle, during phase one of the STS transfer, between the involved and uninvolved limbs of the CON group was characterised as a small difference before (ES= 0.48) and after (ES= 0.45) the rehabilitation intervention. The effect size for the difference in the peak hip Abd/Add angle, during phase two of the STS transfer, between the involved and uninvolved limbs of the CON group was characterised as a trivial difference before (ES= 0.07) and a trivial to small difference after (ES= 0.32) the rehabilitation intervention.



**Figure 7.4. A)** A comparison of the peak hip adduction-abduction angle between the ECC and CON intervention groups during phase one of the STS transfer. **B)** A comparison of the peak hip adduction-abduction angle between the ECC and CON intervention groups during phase two of the STS transfer. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; °, degrees.

### **7.3.3 Sit-To-Stand Electromyography**

#### **7.3.3.1 The Vastus Medialis Muscle**

There were no significant differences in the pre- to post-intervention change in VM muscle activity between the ECC group and the CON group for their involved limb (ECC group +0.43%, CON group +11.63%,  $P= 0.198$ ) and uninvolved limb (ECC group -0.30%, CON group +6.85%,  $P= 0.307$ ) (Figure 7.5).

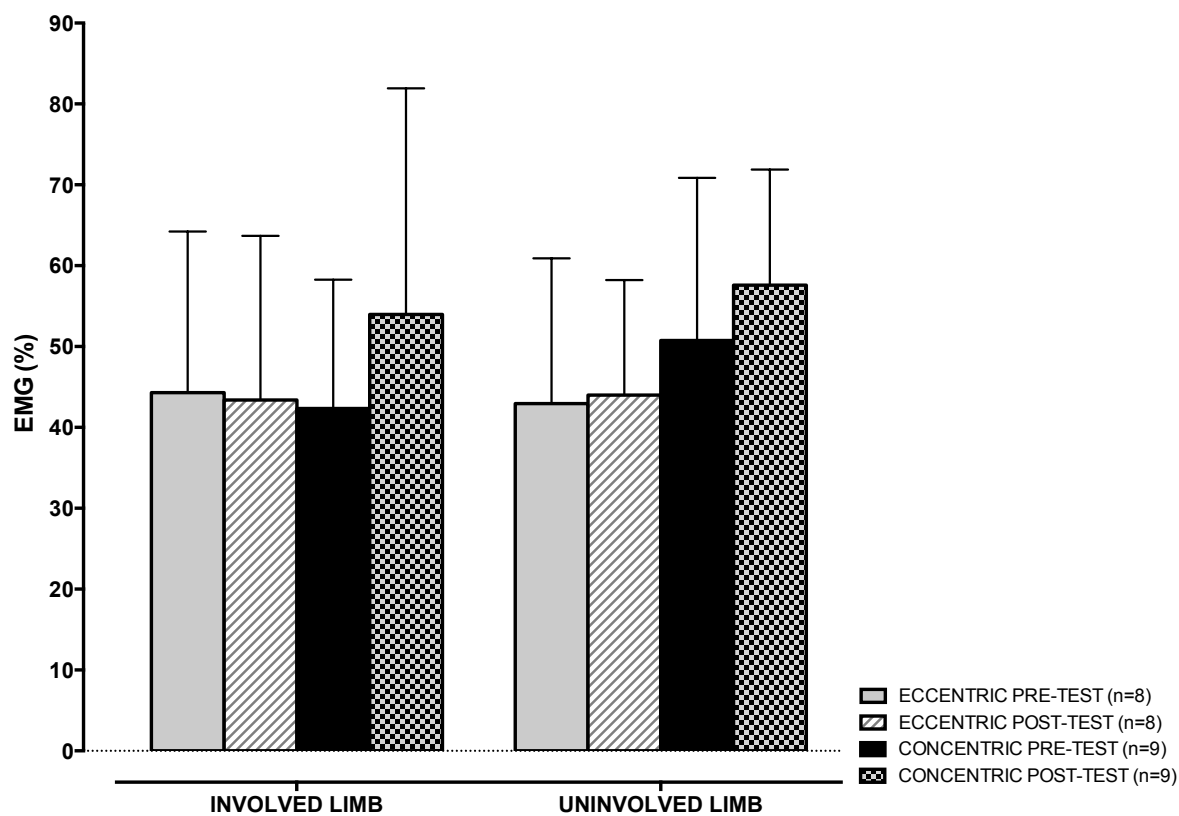
There were no significant changes in VM muscle activity as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.963$ ; CON group  $P= 0.324$ ) and the uninvolved limb (ECC group  $P= 0.324$ ; CON group  $P= 0.446$ ) from the pre to the post-intervention test.

There were no significant differences in VM muscle activity between the involved and uninvolved limbs of the ECC group before (Involved,  $42.95 \pm 17.95\%$ ; Uninvolved,  $44.29 \pm 19.93\%$ ;  $P= 0.883$ ) and after (Involved,  $43.38 \pm 20.31\%$ ; Uninvolved,  $43.99 \pm 14.24\%$ ;  $P= 0.942$ ) the rehabilitation intervention. There were no significant differences in VM muscle activity between the involved and uninvolved limbs of the CON group before (Involved,  $42.33 \pm 15.94\%$ ; Uninvolved,  $50.74 \pm 20.11\%$ ;  $P= 0.370$ ) and after (Involved,  $53.58 \pm 27.96\%$ ; Uninvolved,  $57.58 \pm 14.30\%$ ;  $P= 0.749$ ) the rehabilitation intervention.

The effect size for the pre- to post-intervention change in VM muscle activity of the involved limb (ES= 0.70) was characterised as a small to moderate difference between the ECC and CON groups. The effect size for the pre- to post-intervention change in VM muscle activity of the uninvolved limb (ES= 0.36) was characterised as a small difference between the ECC and CON groups.

The effect size for the change in the VM muscle activity of the ECC group was characterised as a trivial to small difference for the involved limb (ES= 0.02) and the uninvolved limb (ES= 0.02), from the pre- to post-intervention test. The effect size for the change in the VM muscle activity of the CON group was characterised as a small to moderate difference for the involved limb (ES= 0.53), and a trivial to small difference for the uninvolved limb (ES= 0.40), from the pre- to post-intervention test.

The effect size for the difference in the VM muscle activity between the involved and uninvolved limbs of the ECC group was characterised as a trivial difference before (ES= 0.07) and after (ES= 0.04) the rehabilitation intervention. The effect size for the difference in the VM muscle between the involved and uninvolved limbs of the CON group was characterised as a trivial to small difference before (ES= 0.47) and after (ES= 0.17) the rehabilitation intervention.



**Figure 7.5.** A comparison of the VM muscle activity between the ECC and CON intervention group. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; %, percentage.

### 7.3.3.2 The Vastus Lateralis Muscle

There were no significant differences in the pre- to post-intervention change in VL muscle activity between the ECC group and the CON group for their involved limb (ECC group -0.18%, CON group -1.06%,  $P= 0.936$ ) and uninvolved limb (ECC group -6.09%, CON group +6.06%,  $P= 0.166$ ) (Figure 7.6).

There were no significant changes in VL muscle activity as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.985$ ; CON group  $P= 0.937$ ) and the uninvolved limb (ECC group  $P= 0.434$ ; CON group  $P= 0.538$ ) from the pre to the post-intervention test.

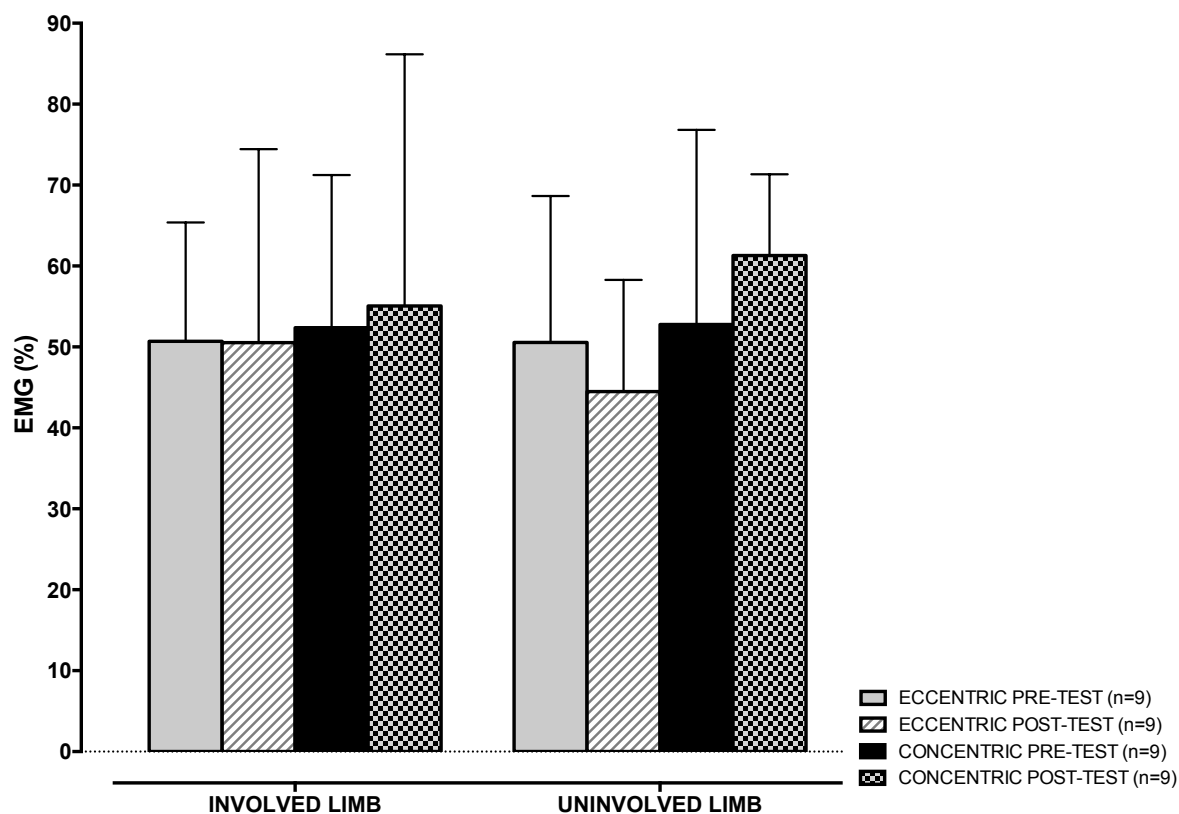
There were no significant differences in VL muscle activity between the involved and uninvolved limbs of the ECC group before (Involved,  $50.70 \pm 14.67\%$ ; Uninvolved,  $50.57 \pm 18.09\%$ ;  $P= 0.986$ ) and after (Involved,  $50.52 \pm 23.91\%$ ; Uninvolved,  $44.48 \pm 13.80\%$ ;  $P= 0.521$ ) the rehabilitation intervention. There were no significant differences in VL muscle activity between the involved and uninvolved limbs of the CON group before (Involved,  $56.13 \pm 20.43\%$ ; Uninvolved,  $52.78 \pm 24.02\%$ ;  $P= 0.775$ ) and after (Involved,  $55.07 \pm 31.09\%$ ; Uninvolved,  $58.84 \pm 7.88\%$ ;  $P= 0.761$ ) the rehabilitation intervention.

The effect size for the pre- to post-intervention change in VL muscle activity of the uninvolved limb ( $ES= 0.51$ ) was characterised as a small to moderate difference between the ECC and CON groups. The effect size for the pre- to post-intervention

change in VL muscle activity of involved limb (ES= 0.04) was characterised as trivial difference between the ECC and CON groups.

The effect size for the change in the VL muscle activity of the ECC group was characterised as a trivial to small difference for the involved limb (ES= 0.01) and the uninvolved limb (ES= 0.38), from the pre- to post-intervention test. The effect size for the change in the VL muscle activity of the CON group was characterised as a small difference for the uninvolved limb (ES= 0.38), and a trivial to small difference for the involved limb (ES= 0.04), from the pre- to post-intervention test.

The effect size for the difference in the VL muscle activity between the involved and uninvolved limbs of the ECC group was characterised as a trivial difference before (ES= 0.01) and a small difference after (ES= 0.32) the rehabilitation intervention. The effect size for the difference in the VL muscle between the involved and uninvolved limbs of the CON group was characterised as a trivial to small difference before (ES= 0.15) and after (ES= 0.19) the rehabilitation intervention.



**Figure 7.6.** A comparison of the VL muscle activity between the ECC and CON intervention group. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; %, percentage.

### 7.3.3.3 The Biceps Femoris Muscle

There were no significant differences in the pre- to post-intervention change in BF muscle activity between the ECC group and the CON group for their involved limb (ECC group -0.93%, CON group -2.58%,  $P= 0.645$ ) and uninvolved limb (ECC group +0.07%, CON group +2.86%,  $P= 0.409$ ) (Figure 7.7).

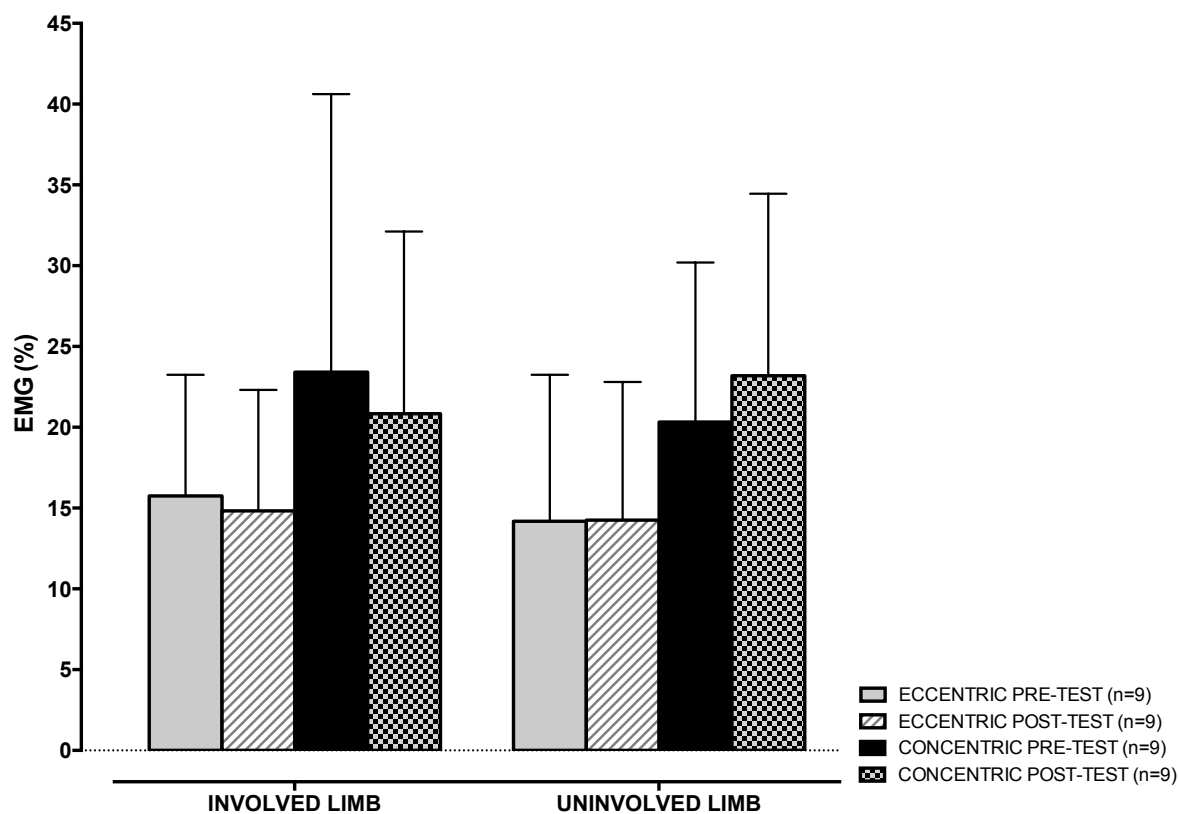
There were no significant changes in BF muscle activity as a result of the respective interventions in either the ECC or CON groups for the involved limb (ECC group  $P= 0.796$ ; CON group  $P= 0.728$ ) and the uninvolved limb (ECC group  $P= 0.986$ ; CON group  $P= 0.597$ ) from the pre to the post-intervention test.

There were no significant differences in BF muscle activity between the involved and uninvolved limbs of the ECC group before (Involved,  $15.75 \pm 7.49\%$ ; Uninvolved,  $14.17 \pm 9.06\%$ ;  $P= 0.694$ ) and after (Involved,  $14.82 \pm 7.49\%$ ; Uninvolved,  $14.25 \pm 8.55\%$ ;  $P= 0.882$ ) the rehabilitation intervention. There were no significant differences in BF muscle activity between the involved and uninvolved limbs of the CON group before (Involved,  $23.42 \pm 17.12\%$ ; Uninvolved,  $20.33 \pm 9.87\%$ ;  $P= 0.667$ ) and after (Involved,  $20.19 \pm 11.28\%$ ; Uninvolved,  $23.19 \pm 11.27\%$ ;  $P= 0.683$ ) the rehabilitation intervention.

The effect size for the pre- to post-intervention change in BF muscle activity of the involved limb ( $ES= 0.10$ ) and uninvolved limb ( $ES= 0.28$ ) was characterised as a trivial to small difference between the ECC and CON groups.

The effect size for the change in the BF muscle activity of the ECC group was characterised as a trivial to small difference for the involved limb (ES= 0.12) and the uninvolved limb (ES= 0.01), from the pre- to post-intervention test. The effect size for the change in the BF muscle activity of the CON group was characterised as a trivial to small difference for the involved limb (ES= 0.18) and the uninvolved limb (ES= 0.27), from the pre- to post-intervention test.

The effect size for the difference in the BF muscle activity between the involved and uninvolved limbs of the ECC group was characterised as a trivial to small difference before (ES= 0.19) and a trivial difference after (ES= 0.07) the rehabilitation intervention. The effect size for the difference in the BF muscle between the involved and uninvolved limbs of the CON group was characterised as a trivial to small difference before (ES= 0.23) and a trivial difference after (ES= 0.21) the rehabilitation intervention.



**Figure 7.7.** A comparison of the BF muscle activity between the ECC and CON intervention group. Abbreviations: ECC, eccentric intervention group; CON, concentric intervention group; n, number of participants; %, percentage.

## 7.4 DISCUSSION

This exploratory study describes ground reaction forces, hip and knee joint kinematics and muscle activity within the two rehabilitation intervention groups during a STS transfer. The main findings of this study show that the participants from both intervention groups continue to shift their weight to the uninvolved limb during the STS transfer following the rehabilitation interventions. These results imply that the participants in both groups are still favouring their involved limbs. This may be a result of remaining muscle strength deficits or subconscious compensatory mechanisms following a total knee arthroplasty. There were no further statistically significant differences between the involved or uninvolved limbs, or as a result of the rehabilitation interventions. This finding was also evident in a clinical study conducted by Mizner et al. (2005) whereby the TKA participants continued to shift their weight away from the operated limb. It was concluded that quadriceps weakness in participants with TKA has a substantial impact on the movement patterns and performance of the knee during functionally important tasks.

The eccentric (ECC) and concentric (CON) intervention groups show a moderate effect size increase in the knee valgus angle following the rehabilitation intervention in comparison to the uninvolved limb. This indicates that following the rehabilitation interventions; the knee of the involved limbs may increase the valgus angle or inward movement during the initial phase of the STS transfer. Since this finding was not statistically significant in this study, further investigation is required to determine its statistical significance. The reason for this is unknown and additional research is required to further investigate the effect of eccentric rehabilitation on the knee

Var/Val angle during the STS transfer. To our knowledge, there are no studies that have described and compared the knee valgus-varus (Val/Var) angles in participant's post-TKA surgery during the STS transfer and this study may serve as starting point for future investigations.

Although there were no significant differences as a result of the rehabilitation interventions, there was a tendency towards a significant difference in the pre- to post-intervention change in the peak hip abduction-adduction (Abd/Add) angle of the involved limb, whereby the ECC group shows an increase in peak hip adduction whilst the CON group shows an increase in hip abduction angle from the pre- to post-intervention test. Correspondingly, the results show a moderate difference in the peak hip Abd/Add angle of the involved limb during phase one of the STS transfer, between the ECC and CON intervention group. Additionally, there is a moderate difference in the peak hip Abd/Add angle, during phase one of the STS transfers, between the involved and uninvolved limb following the ECC rehabilitation intervention. The reason behind these results is not yet known however a study conducted by Hoglund et al. (2009) showed that participants with patellofemoral osteoarthritis (PFOA) had increased hip abduction during the STS transfer, in comparison to control participants, and that this may serve as a compensatory action in an attempt to prevent the knee from collapsing medially during the STS transfer. Additionally, obesity has been associated with increased hip abduction angles during the STS transfer (Huffman et al. 2015). These results suggest that an increase in hip abduction angle during the sit-to-stand transfer is associated with conditions such as obesity and PFOA and may not be a favourable outcome. Since this finding was not

statistically significant in this study, further investigation is required to determine its statistical and clinical significance.

The limitations of this study include a relatively small sample size (18 participants), which may have reduced statistical power, as well as large standard deviations due to the heterogeneity of the patient population as described in section 5.4. These high standard deviations may play a role in the lack of statistical significance found in this study.

In summary, the eccentric and concentric intervention groups show similar patterns of change following the rehabilitation interventions (Figure 7.8). Such as, they both continue to shift their weight away from their involved limb and are associated with an increased medial movement of the knee (knee valgus angle) during the initial phase of the STS. The concentric rehabilitation intervention was associated with increased hip adduction angles during the first phase of the STS, which has also been associated with PFOA and participant's with high BMI. This research study serves as an introductory investigation into the use of the STS as a tool to measure functional performance following an eccentric rehabilitation intervention. Further research is required to fully understand the influence eccentric versus concentric rehabilitation has on the functional ability of participants following a total knee arthroplasty.



**Figure 7.8.** An infographic summarising the conclusions of Study 4.

## CHAPTER 8

### SUMMARY AND CONCLUSIONS

#### 8.1 OVERVIEW

As mentioned previously, due to the large amount of data collected during this thesis, the results were presented in four separate studies, however the same participants were used throughout the data collection period. This was simply a means to present the results in a way that is easy to follow and understand. The overall objectives of this thesis were to determine if an eccentric cycling ergometry rehabilitation intervention (a) was tolerated within participants three to nine months after TKA surgery (Study 1), (b) resulted in greater improvements in muscle strength and endurance, as well as muscle activity and muscle volume (Study 2) and, (c) resulted in greater knee functional ability, health related quality of life and physical activity levels (Study 3), when compared to an concentric cycling ergometry rehabilitation intervention. Additionally, knee and hip kinematics, ground reaction force and muscle activity were described during the sit-to-stand transfer within this population (Study 4).

##### **8.1.1 STUDY 1: THE FEASIBILITY OF AN ECCENTRIC VERSUS CONCENTRIC CYCLING ERGOMETRY REHABILITATION INTERVENTION IN PATIENTS POST TOTAL KNEE ARTHROPLASTY.**

The primary objective of chapter 4 was to investigate pain, heart rate, and workload of an eccentric compared with a concentric rehabilitation intervention, matched in

duration and perceived exertion, in participant's as early as three months post total knee arthroplasty. In summary, the data showed that:

- (i) The eccentric intervention group achieved a significantly greater overall power and work output when compared to the concentric intervention group following the rehabilitation intervention.
- (ii) The eccentric intervention group achieved a significantly lower heart rate over the intervention period in comparison to the concentric intervention group.
- (iii) The eccentric rehabilitation intervention was found to be feasible in participants as early as three months post-TKA and was well tolerated with regards to perception of pain.

In conclusion, as both the rehabilitation interventions were well tolerated with respect to the level of pain, it is inferred that both the concentric and eccentric rehabilitation interventions are feasible therapeutic modalities within participants as early as three months post-TKA surgery. However, due to the significantly greater power output produced and work performed at significantly lower heart rates, it was proposed that the eccentric rehabilitation intervention is a viable exercise intervention within participant's as early as three months post-TKA surgery and may also elicit superior gains in functional performance. This is noteworthy as, in cases where physical and cardiovascular capacity is limited, it is vital to identify means of improving functional performance whilst minimising the stress placed on the cardiovascular system. The

objectives of the following chapters in this thesis were to establish the efficacy of this exercise intervention.

### **8.1.2 STUDY 2: THE EFFECTS OF AN ECCENTRIC VERSUS CONCENTRIC CYCLING ERGOMETRY REHABILITATION INTERVENTION ON MUSCLE STRENGTH, VOLUME AND ACTIVITY IN PATIENTS POST TOTAL KNEE ARTHROPLASTY.**

The aim of chapter 5 was to investigate the effects of an eccentric versus concentric cycling ergometry rehabilitation intervention on muscle strength, volume and activity in participant's as early as three months post total knee arthroplasty. In summary, the data showed that:

- (i) Eccentric training was associated with greater improvements in hamstring muscle efficiency during concentric contractions from the pre- to post-intervention test.
- (ii) Concentric training resulted in greater improvements in vastus lateralis muscle efficiency during concentric contractions from the pre- to post-intervention test.
- (iii) Concentric training resulted in a significant increase in the lean thigh volume of the involved limb from the pre- to post-intervention test.
- (iv) The eccentric and concentric training was associated with an increase in the lean thigh volume of the uninvolved limb from the pre- to post-intervention test.

- (v) There was no evidence of significant change in muscle strength for the eccentric and concentric training.

In summary, this study suggests that eccentric training performed with matched perceived exertion may be associated with greater improvements in hamstring muscle efficiency during concentric contractions in comparison to concentric training. Alternatively, concentric training may be associated with greater gains in muscle area and quadriceps muscle efficiency during concentric contractions. However, it is important to note that strength gains after eccentric training are highly specific to the mode of contraction as well as the intensity of training. Additionally, the neural specificity of eccentric exercise may compromise the transferability of strength gains to concentric type muscle movements. Further research is required to investigate the extent to which training specificity influences the transferability of strength gains to activities of daily living.

### **8.1.3 STUDY 3: THE EFFECT OF AN ECCENTRIC VERSUS CONCENTRIC CYCLING ERGOMETRY REHABILITATION INTERVENTION ON SELF REPORT PHYSICAL AND MENTAL HEALTH SURVEYS IN PATIENTS POST TOTAL KNEE ARTHROPLASTY**

The purpose of chapter 6 was to determine if an eccentric cycling exercise intervention produced greater improvements in knee function, perception of overall wellbeing and quality of life, and level of physical activity when compared to the concentric exercise intervention in participant's as early as three months post total knee arthroplasty. In summary, the data showed that:

- (i) Eccentric training resulted in a significant increase in the level of physical activity from the pre- to post-intervention test.
- (ii) The eccentric rehabilitation intervention was associated with increases in the physical functioning components of the SF-36 health survey, from the pre- to post-intervention test.
- (iii) The eccentric and concentric training was associated with increases in the participation level in sport and recreational activities from the pre- to post-intervention test.

In summary, the results suggest that eccentric training elicits greater improvements in physical functioning and levels of activity, however both rehabilitation interventions show similar patterns of change. Further research is required to investigate the effects of eccentric and concentric ergometry on the perception of overall wellbeing, quality of life, and level of physical activity in participants post total knee arthroplasty.

#### **8.1.4 STUDY 4: THE SIT-TO-STAND TRANSFER IN PATIENTS POST TOTAL KNEE ARTHROPLASTY AFTER EITHER AN ECCENTRIC OR CONCENTRIC REHABILITATION INTERVENTION: AN EXPLORATORY STUDY**

The primary purpose of chapter 7 was to describe and compare the sit-to-stand (STS) transfer using kinematic and kinetic data of participant's as early as three months post-TKA surgery randomised into a concentrically or eccentrically biased rehabilitation intervention. Specifically, we would like to describe the vertical and

anterior-posterior ground reaction forces, hip abduction-adduction and knee valgus-varus joint angles, as well as the muscle activity in the vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) of both the involved and uninvolved limbs. In summary, the data showed that:

- (i) The participants from both the eccentric and concentric group continued to shift their weight to the uninvolved limb during the sit-to-stand transfer following the rehabilitation interventions.
- (ii) There was no evidence of significant change in the kinematic data following the eccentric and concentric training.
- (iii) Both the eccentric and concentric rehabilitation interventions were associated with increased peak knee valgus angle of the involved limb during phase one of the STS transfer.
- (iv) Concentric training was associated with increased hip adduction angles of the involved limb during phase one of the sit-to-stand transfer.

In summary, the eccentric and concentric intervention groups show similar patterns of change following the rehabilitation interventions, where they both continue to shift their weight away from their involved limb and are associated with an increased medial movement of the knee (knee valgus angle) during the initial phase of the STS. The concentric rehabilitation intervention was also associated with increased hip adduction angles during the first phase of the STS. The reason for this unknown

and since this finding was not statistically significant in this study; further investigation is required to determine its statistical significance. To our knowledge, there are no studies that have described and compared the knee valgus-varus angles in participant's post-TKA surgery during the STS transfer. This study may serve as starting point for future investigations.

This research study serves as an introductory investigation into the effect of an eccentric versus concentric ergometry rehabilitation intervention on the ability to perform a STS transfer. Further research is required to fully understand the influence of eccentric versus concentric rehabilitation has on the functional ability of participants following a total knee arthroplasty.

## 8.2 LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The focus of this research was to determine if an eccentric cycling rehabilitation intervention resulted in greater improvements in the physical functioning of participants post total knee arthroplasty, when compared to a concentric cycling rehabilitation intervention. It has been suggested that strength gains after eccentric training are highly specific to the mode of contraction as well as the intensity of training (Roig et al. 2009). However, the strength outputs were only assessed during concentric isokinetic testing. This may have been a limitation that could have resulted in certain benefits of the eccentric training being overlooked.

Additionally, the participant's age ranged from 30 to 80 years old, with greatly varied functional abilities. Due to this heterogeneity, the standard deviations were larger than anticipated. The inclusion criteria did not account for the wide range of physical and functional ability of the participant's included in this thesis. These high standard deviations along with the relatively small sample size (18 participants) may have lead to reduced statistical power and play a role in the few significant findings being found in this thesis.

An initial suggestion for future research is to investigate a larger and/or more homogenous sample of the TKA population. The inclusion criteria should be more stringent with regards to functional ability prior to the rehabilitation intervention or alternatively, participants could be grouped according to functional level as a means to reduce intragroup variation.

It has been suggested that adaptation to concentric and eccentric training is highly dependent on the muscle action used for training and testing and therefore the high specificity of eccentric training has to be taken into account when gains in total strength are interpreted (Roig et al. 2009). Thus, when comparing the effects of eccentric versus concentric training, the inclusion of both concentric and eccentric isokinetic strength testing is suggested as a means to identify specific strength gains following rehabilitation.

The results of study 2 indicated that the eccentric cycling rehabilitation intervention might be associated with greater hamstring muscle efficiency during concentric contractions, whilst the concentric cycling rehabilitation intervention resulted in greater quadriceps muscle efficiency during concentric contractions. This may have implications when prescribing rehabilitation interventions for specific muscle groups in participant's post-TKA. Since these findings were not statistically significant and there was no evidence for significant improvement in strength outcomes, further investigation is required to determine the statistical and clinical significance. Additionally, the results of study 2 indicated that the concentric training resulted in increased lean thigh volume. However, existing research suggests eccentric training appeared to be more effective in promoting overall increases in muscle mass. As previously mentioned, few studies have investigated the effects of eccentric versus concentric training that is matched in exercise intensity. Thus, suggestions for future research include a more in depth investigation in to the effects of an eccentric rehabilitation intervention on muscle volume in comparison to a concentric rehabilitation intervention that is matched in intensity in participants post-TKA and other patients populations.

The results of study 4 indicated that following the rehabilitation interventions; the knee of the involved limbs may increase the valgus angle or inward movement during the initial phase of the STS transfer. The reason for this is unknown and additional research is required to further investigate the effect of eccentric rehabilitation on the knee Var/Val angle during the STS transfer. Since this finding was not statistically significant in this study, further investigation is required to determine its statistical significance. To our knowledge, there are no studies that have described and compared the knee valgus-varus (Val/Var) angles in participant's post-TKA surgery during the STS transfer. This study may serve as starting point for future investigations.

Additionally, the results of study 4 showed that the concentric rehabilitation intervention was associated with increased hip adduction angles during the first phase of the STS, which has also been associated with PFOA and participant's with high BMI (Hogland et al. 2009; Huffman et al. 2015). As this finding was not statistically significant, further investigation is required to determine the statistical and clinical significance as well as investigate the possible implications of finding. This research study serves as an introductory investigation into the use of the STS as a tool to measure functional performance following an eccentric rehabilitation intervention and further research is required to fully understand the influence eccentric versus concentric rehabilitation has on the functional ability of participants following a total knee arthroplasty.

### 8.3 CLINICAL APPLICATIONS

The overall aim of this thesis was to investigate the effects of an eccentric training on the restoration of functional ability in participants post total knee arthroplasty.

The results of this thesis showed that both the eccentric and concentric training were feasible in participants as early as three months post-TKA. The eccentric training resulted in greater improvements in the level of physical activity and functioning compared to the concentric training. Additionally, due to the significantly greater power output produced and work performed at significantly lower heart rates, it may be proposed that the eccentric rehabilitation intervention is a viable exercise intervention within participants as soon as three months after TKA surgery and may elicit superior gains in functional performance. This is exceedingly noteworthy as, in cases where physical and cardiovascular capacity is limited, it is vital to identify means of improving physical and functional performance while minimising the stress placed on the cardiovascular system.

However, despite the apparent advantages of the eccentric training, the results of this thesis showed that there were no clear benefits of either the eccentric or the concentric interventions in the restoration of knee function in participant's post-TKA. There may be a number of factors as to why clear improvements in strength, volume and activity were not evident in this thesis. Firstly, there may be underlying factors present in the TKA population that make the process of gaining strength more complicated.

As previously discussed in section 1.3.1, the reduction in quadriceps strength may be a result of a number of factors. These include a limitation of post-operative physical activity (Berth et al. 2002; Silva et al. 2003; Walsh et al. 1998; Yoshida et al. 2008), pre-existing quadriceps weakness associated with OA (Fisher et al. 1991; Lewek et al. 2004; O'Reilly et al. 1998; Slemenda et al. 1997), trauma related to the surgical procedure (Bonutti et al. 2004; Scuderi et al. 2004), and age related limitations of muscle recovery (Forrest et al. 2003; McArdle et al. 2002; Watters et al. 1993). Furthermore, it has been suggested that a combination of muscle atrophy and neuromuscular activation deficits contribute to the residual quadriceps strength improvements (Mizner et al. 2005a). These existing physical and functional limitations within the patient population may delay or hinder improvements in strength related outcomes. Additionally, each TKA patient may present with diverse medical histories as well as different limitations to physical activity. These may include different mechanisms of injury and reasons for TKA surgery that may influence the outcome of surgery, as well as different demographic characteristics such as age that may limit the potential for performance improvement. Therefore a standardised intervention may not be the best approach when working with such a diverse population. Thus, the clinician should be aware of the importance of individualised patient assessment and exercise prescription and that emphasis should be placed on the understanding and consideration of the specific needs and goals of each TKA patient in order to achieve the best performance outcomes.

Additionally, the loss of strength in the quadriceps prior to surgery may also be related to a decrease in muscle mass and strength post-TKA as well as an inability to fully activate the quadriceps muscles following TKA surgery (Berth et al. 2002; Mizner et al. 2003; Perhonen et al. 1992; Stevens et al. 2003). A widely held belief as to why the patient experiences such quadriceps strength deficits, specifically early after surgery, is that pain associated with the surgery itself induces a diminished capacity to voluntarily activate the muscles. This is commonly known as muscle inhibition and it refers to the inability to fully recruit and activate all the muscle's available motor units, resulting in a decreased or absent muscle contraction (Kent-Braun & Le Blanc 1996). Preliminary studies have confirmed that this reduction in muscle activation is a significant factor contributing to the post-operative muscle weakness (Perhonen et al. 1992; Stevens et al. 2003). Therefore, it is important for the clinician to acknowledge that pain may limit force production and the ability to fully recruit and activate all the muscle's available motor units and that this may serve as a possible mechanism, which may explain poor patient outcome.

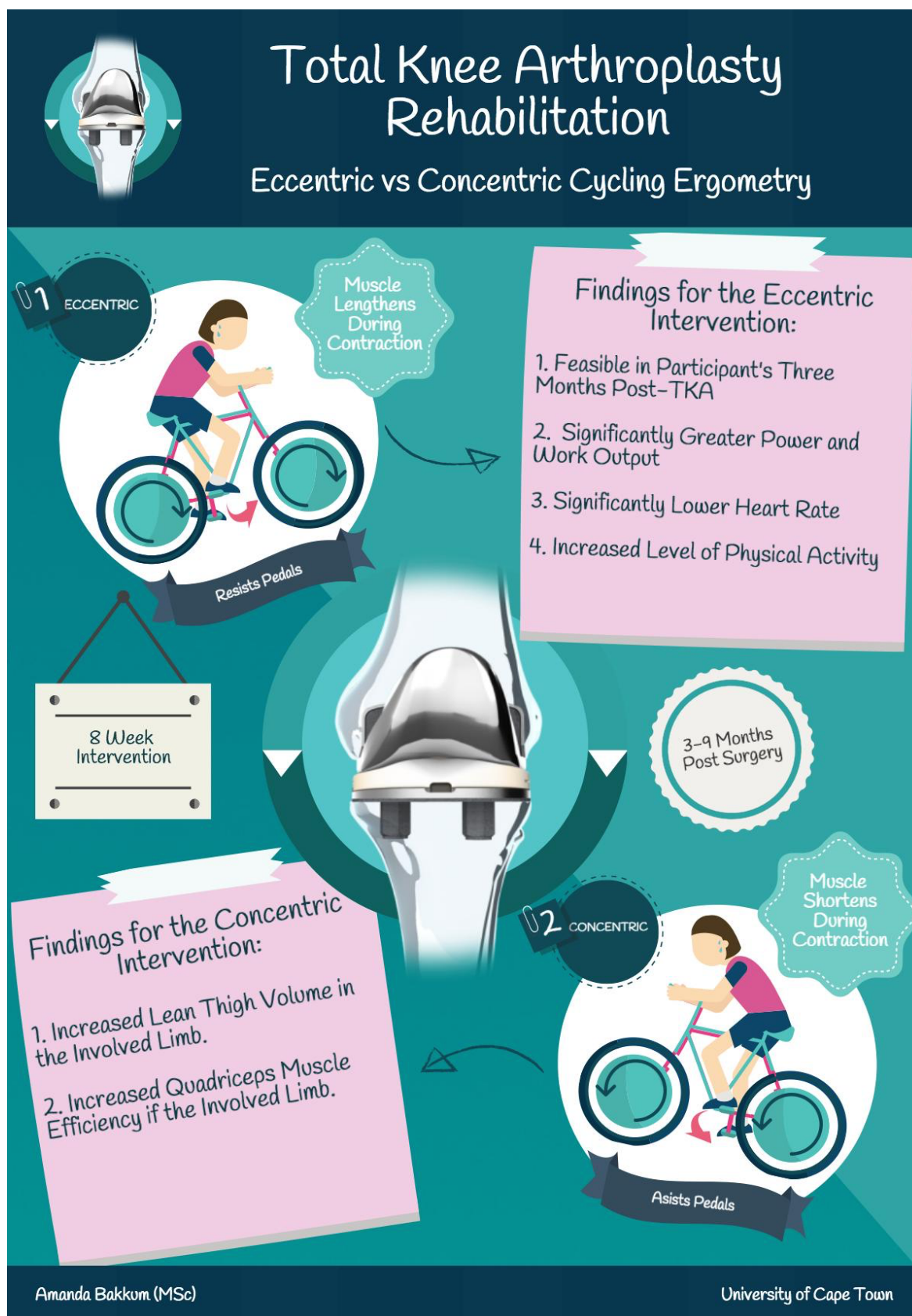
The rehabilitation intervention utilised in this thesis was implemented three to nine months post-TKA and lasted for eight weeks. A possible explanation may be that the implementation of the intervention was too late following surgery. It has been suggested that rehabilitation be implemented early following TKA surgery in order to offset or reduce any further reduction in quadriceps strength early after surgery. As pain was not a limiting factor, the intervention may have been implemented sooner following TKA surgery. Another factor to consider is that the intervention may not have been implemented over a long enough period of time to produce meaningful gains in muscle strength. Alternatively, the intervention may not have been at a high

enough intensity to offset muscle strength deficits and allow for adequate strength improvement. Therefore, since this intervention was well tolerated at three months post-TKA, clinicians could implement interventions earlier after surgery and at a higher level of intensity.

## 8.4 CONCLUSION

In conclusion, as both the rehabilitation interventions were well tolerated with respect to the level of pain, it is inferred that both the concentric and eccentric rehabilitation interventions are feasible therapeutic modalities within participants as early as three months post-TKA surgery. However, due to the significantly greater power output produced and work performed at significantly lower heart rates, it was proposed that the eccentric rehabilitation intervention is a viable exercise intervention within participant's as early as three months post-TKA surgery and may also elicit superior gains in functional performance (Figure 8.1).

The eccentric training resulted in greater improvements in the physical activity level of the participants in comparison to the concentric training. This has positive implications in everyday life and may influence overall patient wellbeing, however there was no evidence for improvement in objective physical functioning measures. The concentric training resulted in improved quadriceps muscle efficiency and endurance as well as increased lean thigh volume in the involved limb, however there were no meaningful improvements in physical function following the intervention. There was no clear evidence for improvement in strength gains and QoL for either eccentric or concentric training. Further research is required to establish which training modality is the most feasible and effective in restoring knee function in participant's three months post-TKA. It is important to note that when selecting a rehabilitation intervention, it is important to understand and consider the specific needs and goals of the participant in order to achieve the best performance outcomes.



**Figure 8.1.** An infographic summarising the conclusions of this thesis.

## REFERENCES

- Abbott BC, Bigland B, and Ritchie JM.** The Physiological Cost of Negative Work. *The Journal of Physiology*, (1901), pp.380–390,1952.
- Avramidis, K. Strike, PW, Taylor, PN and Swain, ID,** Effectiveness of electric stimulation of the vastus medialis muscle in the rehabilitation of patients after total knee arthroplasty. *Archives of Physical Medicine and Rehabilitation*, 84(12), pp.1850–1853, 2003.
- Ayers DC, Franklin PD, Trief PM, Ploutz-Snyder R, Freund D.** Psychological attributes of preoperative total joint replacement patients: implications for optimal physical outcome. *The Journal of Arthroplasty*, 19(7), pp.125–130, 2004.
- Bandholm T and Kehlet H.** Physiotherapy exercise after fast-track total hip and knee arthroplasty: time for reconsideration? *Archives of Physical Medicine and Rehabilitation*, 93(7), pp.1292–4, 2012.
- Barrois B, Ribinik P, Gougeon F, Rannou F and Revel, M.** What is the role of the physical medicine and rehabilitation unit after total knee arthroplasty? Clinical practice recommendations. *Annals of Physical and Rehabilitation Medicine*, 50(9), pp.724–728,729–733, 2007.
- Berth A, Urbach D and Awiszus F.** Improvement of voluntary quadriceps muscle activation after total knee arthroplasty. *Archives of Physical Medicine and Rehabilitation*, 83(10), pp.1432–1436, 2002.
- Bigland-Ritchie B and Woods JJ.** Integrated electromyogram and oxygen uptake during positive and negative work. *The Journal of Physiology*, 260(2), pp.267–277, 1976.
- Bolanos AA, Colizza WA, McCann PD, Gotlin RS, Wootten ME, Kahn BA and Insall JN.** A comparison of isokinetic strength testing and gait analysis in patients with posterior cruciate-retaining and substituting knee arthroplasties. *The Journal of Arthroplasty*, 13(8), pp.906–915,1998.
- Bonutti, PM, Mont MA and Kester MA.** Minimally invasive total knee arthroplasty: a 10-feature evolutionary approach. *The Orthopedic Clinics of North America*, 35(2), pp.217–226, 2004.
- Borg, G.** Borg's Perceived Exertion and Pain Scales. *Human Kinetics*, 1998.
- Brander VA, Stulberg SD, Adams AD, Harden RN, Bruehl S, Stanos SP and Houle T.** Predicting total knee replacement pain: a prospective, observational study. *Clinical Orthopaedics and Related Research*, (416), pp.27–36, 2003.

- Brown T and Hahn ME.** The Emg/Torque Relationship Of The Knee Extensors During Acute Fatigue. In *ASB 29th Annual Meeting*. 2005.
- Bullens PH, van Loon CJ, de Waal Malefijt MC, Laan RF and Veth RP.** Patient satisfaction after total knee arthroplasty: a comparison between subjective and objective outcome assessments. *The Journal of Arthroplasty*, 16(6), pp.740–7, 2001.
- Busse ME, Wiles CM and van Deursen RWM.** Co-activation: its association with weakness and specific neurological pathology. *The Journal of Neuroengineering and Rehabilitation*, 3, pp.26, 2006.
- Callahan CM, Drake BG, Heck DA and Dittus RS.** Patient outcomes following tricompartmental total knee replacement. A meta-analysis. *The Journal Of The American Medical Association*, 271(17), pp.1349–1357, 1994.
- Collins SL, Moore RA and McQuay HJ.** The visual analogue pain intensity scale: what is moderate pain in millimetres? *Pain*, 72(1-2), pp.95-97, 1997.
- Dickstein, R, Heffes Y, Shabtai EI and Markowitz E.** Total knee arthroplasty in the elderly: patients' self-appraisal 6 and 12 months postoperatively. *Gerontologia (Basel)*, 44(4), pp.204–210, 1998.
- Doucet BM, Lam A and Griffin L.** Neuromuscular electrical stimulation for skeletal muscle function. *The Yale Journal of Biology And Medicine*, 85(2), pp.201–15, 2012.
- Drake, R, Vogl AW and Mitchell AWM.** *Gray's Anatomy for Students* 2nd ed., 2009.
- Dufour SP, Lampert E, Doutreleau S, Lonsdorfer-Wolf E, Billat VL, Piquard F and Richard R.** Eccentric cycle exercise: training application of specific circulatory adjustments. *Medicine and Science in Sports and Exercise*: 36(11), pp.1900- 1906, 2004.
- Dufour SP, Doutreleau S, Lonsdorfer-Wolf E, Lampert, E, Hirth C, Piquard F and Richard R.** Deciphering the metabolic and mechanical contributions to the exercise-induced circulatory response: insights from eccentric cycling. *The American of Journal Physiology: Regulatory Integrated Comparative Physiology*, 292(4), pp.1641- 1648, 2006.
- Duncan PW, Chandler JM, Cavanaugh DK, Johnson KR and Buehler AG.** Mode and speed specificity of eccentric and concentric exercise training. *The Journal of Orthopaedic and Sports Physical Therapy*, 11(2), pp.70–75, 1989.
- Eguchi A.** Effect of static stretch on fatigue of lumbar muscles induced by prolonged contraction. *Electromyography Clinical Neurophysiology*, 44(2), pp.75–81, 2004.

- Ethgen O, Bruyère O, Richy F, Dardennes C and Reginster J.** Health-related quality of life in total hip and total knee arthroplasty. A qualitative and systematic review of the literature. *The Journal of Bone and Joint Surgery*, 86-A(5), pp.963–974, 2004.
- Farquhar SJ, Kaufman KR and Snyder-Mackler L.** Sit-to-stand 3 months after unilateral total knee arthroplasty: comparison of self-selected and constrained conditions. *Gait & Posture*, 30(2), pp.187-191, 2009.
- Farquhar SJ, Reisman DS and Snyder-Mackler L.** Persistence of Altered Movement Patterns During a Sit-to-Stand Total Knee Arthroplasty. *Physical Therapy*, 88(5), pp.567–579, 2008.
- Feiring DC, Ellenbecker TS, Derscheid GL.** Test-retest reliability of the biodex isokinetic dynamometer. *The Journal of Orthopaedic and Sports Physical Therapy*, 11(7), pp.298-300, 1990.
- Ferri A, Scaglioni G, Pousson M, Capodaglio P, Van Hoecke J and Narici MV.** Strength and power changes of the human plantar flexors and knee extensors in response to resistance training in old age. *Acta Physiologica Scandinavica*, 177(1), pp.69-78, 2003.
- Fisher NM, Pendergast DR, Gresham GE and Calkins E.** Muscle rehabilitation: its effect on muscular and functional performance of patients with knee osteoarthritis. *Archives of Physical Medicine and Rehabilitation*, 72(6), pp.367–374, 1991.
- Fisher NM, Gresham G and Pendergast DR.** Effects of a quantitative progressive rehabilitation program applied unilaterally to the osteoarthritic knee. *Archives of Physical Medicine and Rehabilitation*, 74(12), pp.1319-1326, 1993.
- Fitzgerald JD, Orav EJ, Lee TH, Marcantonio ER, Poss R, Goldman L and Mangione CM.** Patient quality of life during the 12 months following joint replacement surgery. *Arthritis & Rheumatism*, 51(1), pp.100–109, 2004.
- Forrest GP, Roque JM and Dawodu ST.** Factors affecting length of stay and need for rehabilitation after hip and knee arthroplasty. *The Journal of Arthroplasty*, 21(2), pp.186–190, 2003.
- Franklin PD, Li W and Ayers DC.** Functional outcome after total knee replacement varies with patient attributes. *Clinical Orthopaedics and Related Research*, 466(11), pp.2597–604, 2008.
- Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ and Roubenoff R.** Aging of skeletal muscle: a 12-yr longitudinal study. *The Journal of Applied Physiology*, 88(4), pp.1321–1326, 2000.
- Plug-in Gait.** Vicon Product Guide — Foundation Notes. 2008.

- George LK, Ruiz D and Sloan FA.** The effects of total hip arthroplasty on physical functioning in the older population. *Arthritis & Rheumatism*, 58(10), pp.3166–3171, 2008.
- Gerber JP, Marcus RL, Dibble LE, Greis PE, Burks RT and LaStayo PC.** Effects of early progressive eccentric exercise on muscle structure after anterior cruciate ligament reconstruction. *The Journal of Bone and Joint Surgery*, 89(3), pp.559–570, 2007.
- Gregor JI, Schwenk W, Mall J, Kilian M, Spies C, Bloch A, Müller JM and Rückert JC.** “Fast-track” rehabilitation in thoracic surgery. First experiences with a multimodal, interdisciplinary, and proven perioperative treatment course. *Der Chirurg; Zeitschrift für alle Gebiete der operativen Medizin*, 79(7), pp.657–64, 2008.
- Gür H.** Concentric versus combined concentric-eccentric isokinetic training: Effects on functional capacity and symptoms in patients with osteoarthritis of the knee. *Archives of Physical Medicine and Rehabilitation*, 83(3), pp.308–316, 2002.
- Gür H and Cakin N.** Muscle mass, isokinetic torque, and functional capacity in women with osteoarthritis of the knee. *Archives of Physical Medicine and Rehabilitation*, 84(10), pp.1534–1541, 2003.
- Heck DA, Robinson RL, Partridge CM, Lubitz RM and Freund DA.** Patient outcomes after knee replacement. *Clinical Orthopaedics and Related Research*, 356(356), pp.93–110, 1998.
- Hermens HJ, Freriks B, Disselhorst-Klug C and Rau G.** Development of recommendations for SEMG sensors and sensor placement procedures. *The Journal of Electromyography and Kinesiology*, 10(5), pp.361–374, 2000.
- Den Hertog A, Gliesche K, Timm J, Mühlbauer B and Zebrowski S.** Pathway-controlled fast-track rehabilitation after total knee arthroplasty: a randomized prospective clinical study evaluating the recovery pattern, drug consumption, and length of stay. *Archives of Orthopaedic and Trauma Surgery*, 132(8), pp.1153-1163, 2012.
- Higbie EJ, Cureton KJ, Warren GL and Prior BM.** Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. *The Journal of Applied Physiology*, 81(5), pp.2173–81, 1996.
- Hoglund LT, Barbe MF, Barr AE, Hillstrom HJ, Lockard MA Song J and Reinus WR.** Persons With Patellofemoral Osteoarthritis Exhibit Increased Hip And Knee Moments During A Sit-To-Stand Task. *Arthritis & Rheumatism*, 60, pp.16–21, 2009.
- Holm B, Kristensen MT, Myhrmann L, Husted H, Andersen L, Kristensen B and Kehlet H.** The role of pain for early rehabilitation in fast track total knee arthroplasty. *Disability and Rehabilitation*, 32(4), pp.300–306, 2010.

- Hopkins WG.** Probabilities of clinical or practical significance. *Sportscience*, 6(201), p.589, 2002.
- Hortobágyi T, Dempsey L, Fraser D, Zheng D, Hamilton G, Lambert J and Dohm L.** Changes in muscle strength, muscle fibre size and myofibrillar gene expression after immobilization and retraining in humans. *The Journal of Physiology*, 524(1), pp.293–304, 2000.
- Hsieh L, Didenko B and Schumacher H.** Isokinetic and isometric testing of knee musculature in patients with rheumatoid arthritis with mild knee involvement. *Archives of Physical Medicine and Rehabilitation*, 68, pp.294–297, 1987.
- Huang CH, Cheng CK, Lee YT and Lee KS.** Muscle strength after successful total knee replacement: a 6- to 13-year follow-up. *Clinical Orthopaedics and Related Research*, (328), pp.147–154, 1996.
- Huffman KD, Sanford BA, Zucker-Levin AR, Williams JL and Mihalko WM.** Increased hip abduction in high body mass index subjects during sit-to-stand. *Gait & Posture*, 41(2), pp.640–5, 2015.
- Hurley M and Newham D.** The influence of arthrogenous muscle inhibition on quadriceps rehabilitation of patients with early, unilateral osteoarthritic knees. *The British Journal of Rheumatology*, 32(2), pp.127–131, 1993.
- Israelite C, Berman A and Bosacco S.** Evaluation of total knee arthroplasty using isokinetic testing. *Clinical Orthopaedics and Related Research*, (271), 1991.
- Jaggers JR, Simpson CD, Frost KL, Quesada PM, Topp RV, Swank AM and Nyland JA.** Prehabilitation before knee arthroplasty increases postsurgical function: a case study. *The Journal of Strength & Conditioning Research*, 21(2), pp.632-634, 2007.
- Jenkinson C, Wright L and Coulter A.** Criterion validity and reliability of the SF-36 in a population sample. *Quality of Life Research*, 3(1), pp.7–12, 1994.
- Jones CA, Beaupre A, Johnston DWC and Suarez-Almazor E.** Total joint arthroplasties: current concepts of patient outcomes after surgery. *Rheumatic Diseases Clinics Of North America*, 21(3), pp.71–86, 2007.
- Jones CA, Voaklander DC, Johnston DW and Suarez-Almazor ME.** Health related quality of life outcomes after total hip and knee arthroplasties in a community based population. *The Journal of Rheumatology*, 27(7), pp.1745–1752, 2000.
- Jones KR and Vojir CP.** Determining mild, moderate, and severe pain equivalency across pain-intensity tools in nursing home residents. *Journal of Rehabilitation Research & Development*, 44(2), pp.305–314, 2007.

- Kane RL, Saleh KJ, Wilt TJ and Bershadsky B.** The functional outcomes of total knee arthroplasty. *The Journal of Bone and Joint Surgery*, 87(8), pp.1719–1724, 2005.
- Kannus P.** Isokinetic Evaluation of Muscular Performance. *The International Journal of Sports Medicine*, 15, pp.11–18, 1994.
- Katch VL and Katch FI.** A simple anthropometric method for calculating segmental leg limb volume. *Research Quarterly*, 45(2), pp.211–4, 1974.
- Kay D, St Clair Gibson A, Mitchell MJ, Lambert MI and Noakes TD.** Different neuromuscular recruitment patterns during eccentric, concentric and isometric contractions. *The Journal of Electromyography and Kinesiology*, 10(6), pp.425–31, 2000.
- Kennedy DM, Hanna SE, Stratford PW, Wessel J and Gollish JD.** Preoperative function and gender predict pattern of functional recovery after hip and knee arthroplasty. *The Journal of Arthroplasty*, 21(4), pp.559–566, 2006.
- Kent-Braun JA and Le Blanc R.** Quantitation of central activation failure during maximal voluntary contractions in humans. *Muscle & nerve*, 19(7), pp.861–9, 1996.
- Kiebzak GM, Campbell M and Mauerhan DR.** The SF-36 general health status survey documents the burden of osteoarthritis and the benefits of total joint arthroplasty: but why should we use it? *The American Journal Of Managed Care*, 8(5), pp.463–474, 2002.
- Knapik JJ, Staab JS and Harman EA.** Validity of an anthropometric estimate of thigh muscle cross-sectional area. *Medicine and Science in Sports and Exercise*, 28(12), pp.1523–30, 1996.
- Kramer JF, Speechley M, Bourne R, Rorabeck C and Vaz M.** Comparison of clinic- and home-based rehabilitation programs after total knee arthroplasty. *Clinical Orthopaedics and Related Research*, (410), pp.225–34, 2003.
- Kurtz S, Ong K, Lau E, Mowat F and Halpern M.** Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *The Journal of Bone and Joint Surgery*, 89(4), pp.780–785, 2007.
- Larsson B, Karlsson S, Eriksson M and Gerdle B.** Test-retest reliability of EMG and peak torque during repetitive maximum concentric knee extensions. *The Journal of Electromyography and Kinesiology*, 13(3), pp.281-7, 2003.
- LaStayo PC, Pierotti DJ, Pifer J, Hoppeler H and Lindstedt SL.** Eccentric ergometry: increases in locomotor muscle size and strength at low training intensities. *The American journal of Physiology Regulatory Integrative and Comparative Physiology*, 278(5), pp.1282–1288, 2000.

- Lee JW, Han AR and Kim K.** Effects of rehabilitative horse riding on the Sit-to-Stand action of the adolescent with brain lesions. *The Journal of Exercise Rehabilitation*, 10(1), pp.31–4, 2014.
- Lewek MD, Rudolph KS and Snyder-Mackler L.** Quadriceps femoris muscle weakness and activation failure in patients with symptomatic knee osteoarthritis. *The Journal of Orthopaedic Research*, 22(1), pp.110–115, 2004.
- Leys C, Ley C, Klein O, Bernard P and Licata L.** Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *The Journal of Experimental Social Psychology*, 49(4), pp.764–766, 2013.
- Lindstedt SL, LaStayo PC and Reich TE.** When active muscles lengthen: properties and consequences of eccentric contractions. *The International Journal of Physiology*, 16(3), pp.256–261, 2001.
- Lingard EA, Katz JN, Wright EA and Sledge CB.** Predicting the outcome of total knee arthroplasty. *The Journal of Bone and Joint Surgery*, 86-A(10), pp.2179–2186, 2004.
- Lorentzen JS, Petersen MM, Brot C and Madsen OR.** Early changes in muscle strength after total knee arthroplasty. A 6-month follow-up of 30 knees. *Acta Orthopaedica Scandinavica*, 70(2), pp.176–179, 1999.
- MacLean CL, Taunton JE, Clement DB and Regan W.** Eccentric and concentric isokinetic moment characteristics in the quadriceps and hamstrings of the chronic isolated posterior cruciate ligament injured knee. *The British journal of Sports Medicine*, 43(8), pp.556–68, 2009.
- Marcus RL, Yoshida Y, Meier W, Peters C and Lastayo PC.** An Eccentrically Biased Rehabilitation Program Early after TKA Surgery. *Arthritis*, 2011, pp.1–10, 2011.
- Marx RG, Menezes A, Horovitz L, Jones EC and Warren RF.** A comparison of two time intervals for test-retest reliability of health status instruments. *The Journal of Clinical Epidemiology*, 56(8), pp.730-735, 2003.
- Marx RG, Jones EC, Atwan NC, Closkey RF, Salvati EA and Sculco TP.** Measuring improvement following total hip and knee arthroplasty using patient-based measures of outcome. *The Journal of Bone and Joint Surgery*, 87(9), pp.1999–2005, 2005.
- McArdle A, Vasilaki A and Jackson M.** Exercise and skeletal muscle ageing: cellular and molecular mechanisms. *Ageing Research Reviews*, 1(1), pp.79–93, 2002.
- McDowell I.** *Measuring Health: A Guide to Rating Scales and Questionnaires.* Oxford University Press, 2006.

- McKay C, Prapavessis H and Doherty T.** The Effect of a Prehabilitation Exercise Program on Quadriceps Strength for Patients Undergoing Total Knee Arthroplasty: A Randomized Controlled Pilot Study. *PM&R The Journal Of Injury, Function and Rehabilitation*, 4(9), pp.647-656, 2012.
- Meier W, Mizner RL, Marcus RL, Dibble LE, Peters C and Lastayo PC.** Total knee arthroplasty: muscle impairments, functional limitations, and recommended rehabilitation approaches. *The Journal of Orthopaedic and Sports Physical Therapy*, 38(5), pp.246–256, 2008.
- Meier WA, Marcus RL, Dibble LE, Foreman KB, Peters CL, Mizner RL and LaStayo PC.** The long-term contribution of muscle activation and muscle size to quadriceps weakness following total knee arthroplasty. *The Journal of Geriatric Physical Therapy*, 32(2), pp.79–82, 2009.
- Miller LE, Pierson LM, Nickols-Richardson SM, Wootten DF, Selmon SE, Ramp WK and Herbert WG.** Knee extensor and flexor torque development with concentric and eccentric isokinetic training. *Research Quarterly for Exercise and Sport*, 77(1), pp.58–63, 2006.
- Minns Lowe CJ, Barker KL, Dewey M and Sackley CM.** Effectiveness of physiotherapy exercise after knee arthroplasty for osteoarthritis: systematic review and meta-analysis of randomised controlled trials. *The British Medical Journal*, 335(7624), pp.812, 2007.
- Mintken PE, Carpenter KJ, Eckhoff D, Kohrt WM and Stevens JE.** Early neuromuscular electrical stimulation to optimize quadriceps muscle function following total knee arthroplasty: a case report. *The Journal of Orthopaedic and Sports Physical Therapy*, 37(7), pp. 364-371, 2007.
- Mizner RL, Petterson SC, Stevens JE, Vandenborne K and Snyder-Mackler L.** Early quadriceps strength loss after total knee arthroplasty. The contributions of muscle atrophy and failure of voluntary muscle activation. *The Journal of Bone and Joint Surgery*, 87(5), pp.1047–1053, 2005a.
- Mizner RL, Petterson SC, Stevens JE, Axe MJ and Snyder-Mackler L.** Preoperative quadriceps strength predicts functional ability one year after total knee arthroplasty. *The Journal of Rheumatology*, 32(8), pp.1533–1539, 2005b.
- Mizner RL and Snyder-Mackler L.** Altered loading during walking and sit-to-stand is affected by quadriceps weakness after total knee arthroplasty. *The Journal of Orthopaedic Research*, 23(5), pp.1083–1090, 2005.
- Mizner RL, Stevens JE and Snyder-Mackler L.** Voluntary activation and decreased force production of the quadriceps femoris muscle after total knee arthroplasty. *Physical Therapy*, 83(4), pp.359–365, 2003.

- Moffet H, Collet JP, Shapiro SH, Paradis G, Marquis F and Roy L.** Effectiveness of intensive rehabilitation on functional ability and quality of life after first total knee arthroplasty: A single-blind randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, 87(4), pp.546–556, 2006.
- Mulhall KJ, Ghomrawi HM, Mihalko W, Cui Q and Saleh KJ.** Adverse effects of increased body mass index and weight on survivorship of total knee arthroplasty and subsequent outcomes of revision TKA. *The Journal Of Knee Surgery*, 20(3), pp.199–204, 2007.
- Nilsdotter AK, Toksvig-Larsen S and Roos EM.** A 5 year prospective study of patient-relevant outcomes after total knee replacement. *Osteoarthritis and Cartilage*, 17(5), pp.601–606, 2009.
- O'Reilly SC, Jones A, Muir KR and Doherty M.** Quadriceps weakness in knee osteoarthritis: the effect on pain and disability. *Annals of the Rheumatic Diseases*, 57(10), pp.588–594, 1998.
- Perhonen M, Komi P, Hakkinen K, von Bonsdorff H and Partio E.** Strength training and neuromuscular function in elderly people with total knee endoprosthesis. *The Scandinavian Journal of Medicine & Science in Sports*, 2(4), pp.234–243, 1992.
- Perrey S, Betik A, Candau R, Rouillon JD and Hughson RL.** Comparison of oxygen uptake kinetics during concentric and eccentric cycle exercise. *The Journal of Applied Physiology*, 91(5), pp.2135-2142, 2001.
- Proske U and Morgan DL.** Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *The Journal of Physiology*, 537(2), pp.333–345, 2001.
- Pulido L, Parvizi J, Macgibeny M, Sharkey PF, Purtill JJ, Rothman RH and Hozack WJ.** In hospital complications after total joint arthroplasty. *The Journal of Arthroplasty*, 23(6), pp.139–145, 2008.
- Rajan RA, Pack Y, Jackson H, Gillies C and Asirvatham R.** No need for outpatient physiotherapy following total knee arthroplasty: a randomized trial of 120 patients. *Acta Orthopaedica Scandinavica*, 75(1), pp. 71-73, 2004.
- Riley PO, Schenkman ML, Mann RW and Hodge WA.** Mechanics of a constrained chair-rise. *The Journal of Biomechanics*, 24(1), pp.77–85, 1991.
- Rissanen P, Aro S, Sintonen H, Slätis P and Paavolainen P.** Quality of life and functional ability in hip and knee replacements: a prospective study. *Quality of Life Research*, 5(1), pp.56–64, 1996.
- Rodgers JA, Garvin KL, Walker CW, Morford D, Urban J and Bedard J.** Preoperative physical therapy in primary total knee arthroplasty. *The Journal of Arthroplasty*, 13(4), pp.414–421, 1998.

- Roig M, O'Brien K, Kirk G, Murray R, McKinnon P, Shadgan B and Reid WD.** The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. *The British Journal of Sports Medicine*, 43(8), pp.556–68, 2009.
- Rooks DS, Huang J, Bierbaum BE, Bolus SA, Rubano J, Connolly CE, Alpert S, Iversen, MD and Katz JN.** Effect of preoperative exercise on measures of functional status in men and women undergoing total hip and knee arthroplasty. *Arthritis & Rheumatism*, 55(5), pp.700–708, 2006.
- Roos EM and Toksvig-Larsen S.** Knee injury and Osteoarthritis Outcome Score (KOOS) – validation and comparison to the WOMAC in total knee replacement. *Health and Quality of Life Outcomes*, 1(1), pp.17, 2003.
- Ruiz D Jr, Koenig L, Dall TM, Gallo P, Narzikul A, Parvizi J and Tongue J.** The direct and indirect costs to society of treatment for end-stage knee osteoarthritis. *The Journal of Bone and Joint Surgery*, 95(16), pp.1473-80, 2013.
- Santaguida PL, Hawker GA, Hudak PL, Glazier R, Mahomed NN, Kreder HJ and Coyte PC.** Patient characteristics affecting the prognosis of total hip and knee joint arthroplasty : a systematic review. *The Canadian journal of Surgery*, 51(6), pp.428–36, 2008.
- Schneider PL, Crouter SE and Bassett DR.** Pedometer measures of free-living physical activity: comparison of 13 models. *Medicine and Science in Sports and Exercise*, 36(2), pp. 331-335, 2004.
- Scuderi GR, Tenholder M and Capeci C.** Surgical approaches in mini-incision total knee arthroplasty. *Clinical Orthopaedics and Related Research*, 428, pp.61–67, 2004.
- Seger JY, Arvidsson B and Thorstensson A.** Specific effects of eccentric and concentric training on muscle strength and morphology in humans. *European The Journal of Applied Physiology and Occupational Physiology*, 79(1), pp.49–57, 1998.
- Silva M, Shepherd EF, Jackson WO, Pratt JA, McClung CD and Schmalzried TP.** Knee strength after total knee arthroplasty. *The Journal of Arthroplasty*, 18(5), pp.605–611, 2003.
- Singh JA and Sloan JA.** Health-related quality of life in veterans with prevalent total knee arthroplasty and total hip arthroplasty. *Rheumatology*, 47(12), pp.1826–1831, 2008.
- Slemenda C, Brandt KD, Heilman DK, Mazucca S, Braunstein EM, Katz BP and Wolinsky FD.** Quadriceps weakness and osteoarthritis of the knee. *Annals of Internal Medicine*, 127(2), pp.97–104, 1997.

- Sloan FA, Ruiz D and Platt A.** Changes in functional status among persons over age sixty-five undergoing total knee arthroplasty. *Medical Care*, 47(7), pp.742–748, 2009.
- Smith BE, Askew MJ, Gradisar IA, Gradisar JS and Lew MM.** The effect of patient weight on the functional outcome of total knee arthroplasty. *Clinical Orthopaedics and Related Research*, 276(276), pp.237–244, 1992.
- Stevens JE, Mizner RL and Snyder-Mackler L.** Quadriceps strength and volitional activation before and after total knee arthroplasty for osteoarthritis. *The Journal of Orthopaedic Research*, 21(5), pp.775–779, 2003.
- Stevens-Lapsley JE, Balter JE, Wolfe P, Eckhoff DG and Kohrt WM.** Early neuromuscular electrical stimulation to improve quadriceps muscle strength after total knee arthroplasty: a randomized controlled trial. *Physical Therapy*, 92(2), pp.210–26, 2012.
- Swanenburg J, Koch PP, Meier N and Wirth B.** Function and activity in patients with knee arthroplasty: validity and reliability of a German version of the Lysholm Score and the Tegner Activity Scale. *Swiss Medical Weekly*, 144, 2014.
- Synder M, Kozłowski P, Drobniowski M, Grzegorzewski A and Głowacka A.** The use of Continuous Passive Motion (CPM) in the rehabilitation of patients after total knee arthroplasty. *Ortopedia Traumatologia Rehabilitacja*, 6(3), pp.336–341, 2004.
- Tomberlin JP, Basford JR, Schwen EE, Orte PA, Scott SC, Laughman RK and Ilstrup DM.** Comparative study of isokinetic eccentric and concentric quadriceps training. *The Journal of Orthopaedic and Sports Physical Therapy*, 14(1), pp.31–36, 1991.
- Topp R, Swank AM, Quesada PM, Nyland J and Malkani A.** The effect of prehabilitation exercise on strength and functioning after total knee arthroplasty. *PM&R The Journal Of Injury, Function and Rehabilitation*, 1(8), pp.729–735, 2009.
- Vaughan CL and Davis BL.** *Dynamics of Human Gait*, 1999.
- Vincent KR, Vincent HK, Lee LW and Alfano AP.** Outcomes in total knee arthroplasty patients after inpatient rehabilitation: influence of age and gender. *The American journal of Physical Medicine Rehabilitation*, 85(6), pp.482–489, 2006.
- Vissers MM, Bussmann JB, Verhaar JAN, Busschbach JJV, Bierma-Zeinstra SMA and Reijman M.** Psychological factors affecting the outcome of total hip and knee arthroplasty: a systematic review. *Seminars in Arthritis and Rheumatism*, 41(4), pp.576–588, 2012.

- Volpi E, Nazemi R and Fujita S.** Muscle tissue changes with aging. *Current Opinion in Clinical Nutrition and Metabolic Care*, 7(4), pp.405–410, 2004.
- Walsh M, Woodhouse LJ, Thomas SG and Finch E.** Physical impairments and functional limitations: a comparison of individuals 1 year after total knee arthroplasty with control subjects. *Physical Therapy*, 78(3), pp.248–258, 1998.
- Wang H, Simpson KJ, Ferrara MS, Chamnongkich S, Kinsey T and Mahoney OM.** Biomechanical differences exhibited during sit-to-stand between total knee arthroplasty designs of varying radii. *The Journal of Arthroplasty*, 21(8), pp.1193–1199, 2006.
- Wang H, Simpson KJ, Chamnongkich S, Kinsey T and Mahoney OM.** Biomechanical influence of TKA designs with varying radii on bilateral TKA patients during sit-to-stand. *Dynamic Medicine*, 7, pp.12, 2008.
- Ware JE Jr. and Sherbourne C.** The MOS 36-item short-form health survey (SF-36). Conceptual framework and item selection. *Medical Care*, 30(6), pp.473–483, 1992.
- Ware JE Jr.** Health status and quality of life assessment and the next generation of outcomes measurement. *The Journal for Healthcare Quality*, 21(5), pp.12–17, 1999.
- Ware JE Jr.** SF-36 health survey update. *Spine*, 25(24), pp.3130–3139, 2000.
- Watters JM, Clancey SM, Moulton SB, Briere KM and Zhu JM.** Impaired recovery of strength in older patients after major abdominal surgery. *Annals of Surgery*, 218(3), pp.380–390; discussion 390–393, 1993.
- Whitehead NP, Allen TJ, Morgan DL and Proske U.** Damage to human muscle from eccentric exercise after training with concentric exercise. *The Journal of Physiology*, 512, pp. 615-620, 1998.
- Yoshida Y, Mizner RL, Ramsey DK and Snyder-Mackler L.** Examining outcomes from total knee arthroplasty and the relationship between quadriceps strength and knee function over time. *Clinical Biomechanics*, 23(3), pp.320–328, 2008.

## APPENDIX

## APPENDIX A: INFORMED CONSENT




---

**Department of Human Biology**

UCT/MRC RESEARCH UNIT FOR EXERCISE SCIENCE &amp; SPORTS MEDICINE

Faculty of Health Sciences, University of Cape Town

Private Bag, Rondebosch 7700, South Africa

Tel: + 27 21 650 4561

Fax: + 27 21 686 7530

**TOTAL KNEE ARTHROPLASTY: COMPARISON OF TWO TREATMENT MODALITIES  
USED IN END-STAGE REHABILITATION AFTER TOTAL KNEE ARTHROPLASTY (TKA)**
**INFORMED CONSENT FORM**

I, the undersigned, have been fully informed about the UCT/MRC Research Unit for Exercise Science and Sports Medicine within the Department of Human Biology of the University of Cape Town and the Sports Science Orthopaedic Clinic's study on the comparison of two treatment modalities for end-stage rehabilitation after total knee arthroplasty.

I have undergone total knee replacement surgery and agree to participate in one of two treatment modalities. I understand that if I am deemed fit to participate in an exercise programme, I will be given an exercise programme to follow for 8 weeks and I will be expected to attend three 20 minute exercise sessions for each of the 8 weeks. To avoid bias in the study, I understand that none of the investigators will discuss how the specific exercise programme I have been allocated to differs from the other exercise protocol. I understand that this process will be random (drawing out of a hat). I understand that the exercise treatment I receive may result in discomfort and pain as a result of muscle damage.

I agree to perform all the baseline measurements and assessments prior to starting the exercise protocol and after completing the 8 week exercise protocol. It has been explained to me that I will attend a 30 minute familiarization visit, followed by a 3 hour visit in which I will complete a 6-minute walk test, sit-to-stand test, an isokinetic strength assessment, a gait analysis assessment, an MRI scan of my quadriceps and other questionnaires about my knee. I will again attend an identical 3-hour visit after I have completed the 8-week exercise protocol.

---

The University of Cape Town is committed to policies of equal opportunity and affirmative action  
which are essential to its mission of promoting critical inquiry and scholarship

I understand that all the information that is collected during the study will be treated with the strictest confidentiality and will only be used for scientific research purposes. I have been informed that participation the rehabilitation provided in this study, as well as all the assessments will be provided free of charge. I will not be paid for participating in this trial.

The University of Cape Town (UCT) undertakes that in the event of you suffering any significant deterioration in health or well-being, or from any unexpected sensitivity or toxicity, that is caused by your participation in the study, it will provide immediate medical care. UCT has appropriate insurance cover to provide prompt payment of compensation for any trial-related injury according to the guidelines outlined by the Association of the British Pharmaceutical Industry, ABPI 1991. Broadly-speaking, the ABPI guidelines recommend that the insured company (UCT), without legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study doctor immediately of any side effects and/or injuries during the trial, whether they are research-related or other related complications.

The University of Cape Town (UCT) has an appropriate insurance policy to cover payment for any trial-related injury. You may therefore receive compensation in the event of you sustaining any injury and or a significant deterioration in health Your right in law to claim compensation for injury where you prove negligence is not affected. Copies of these guidelines are available on request.

I agree to participate in the study and I have been informed that I will be free to withdraw from the study at any time if I so wish. I understand that I will receive the overall results of the study. I have read (or where appropriate, have had read to me) and understand the information about this study, and any questions I have asked have been answered to my satisfaction. I agree that research data provided by me or with my permission during the project may be presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used.

---

The University of Cape Town is committed to policies of equal opportunity and affirmative action  
which are essential to its mission of promoting critical inquiry and scholarship

This study was granted Ethics approval from the Faculty of Health Sciences (FHS) Human Research Ethics Committee (REC) at the University of Cape Town. If you have any complaints or queries that the investigator has not been able to answer to your satisfaction, you may contact the **Prof Marc Blockman** from the FHS REC on telephone number **021 406 6452**.

FULL NAME OF  
SUBJECT: \_\_\_\_\_

SUBJECT'S SIGNATURE: \_\_\_\_\_

DATE: \_\_\_\_\_

INVESTIGATOR: \_\_\_\_\_

INVESTIGATOR'S  
SIGNATURE: \_\_\_\_\_

---

The University of Cape Town is committed to policies of equal opportunity and affirmative action  
which are essential to its mission of promoting critical inquiry and scholarship

## APPENDIX B: PATIENT HISTORY

## PATIENT HISTORY

## A. PATIENT DEMOGRAPHIC

1. Age at Time of Surgery: \_\_\_\_\_ Years
2. Gender:            Male        Female
3. Weight:           \_\_\_\_\_ Kilograms
4. Height:           \_\_\_\_\_ Centimeters

## B. MEDICAL HISTORY

1. Have you been diagnosed with one or more Chronic Diseases?  Yes  No

If yes, Please elaborate:

---



---

2. Are you currently on any prescription or non-prescription medication?  Yes  No

If yes, Please elaborate:

---



---

C. KNEE HISTORY (*\*Involved Knee refers to the operative knee.*)

1. Involved Knee:    Right        Left
3. Pre-operative Duration of Symptoms: \_\_\_\_\_ Months    Unknown
4. Activity at Onset of Symptoms/Injury:  Sports  ADL  Work  Motor Accident
- OTHER: (specify) \_\_\_\_\_  Unknown
5. Mechanism of Injury:
 

<input type="checkbox"/> Non-traumatic gradual onset	<input type="checkbox"/> Traumatic non-contact onset
<input type="checkbox"/> Non-traumatic sudden onset	<input type="checkbox"/> Traumatic contact onset

## D. SURGICAL HISTORY:

1. Record any significant surgical procedures of the past *other than in the involved knee*

---



---

2. Previous Cartilage Procedure in the Involved Knee:  No Prior Cartilage Procedure

0–6 Months    6–12 Months    >12 Months    >2 Years    >3 Years

3. Comments on Surgical History:

---



---



---

4. Surgical History. Please indicate the **number of previous procedures in the involved knee** excluding the current total knee replacement):

<b>Medial Compartment Surgical History:</b>		<input type="checkbox"/> <b>No Prior Procedure</b>
<b>Medial Femoral Condyle</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ Osteochondral Autograft _____ Osteochondral Allograft _____ Cell Based Cartilage Procedures _____ Focal HemiCAP Resurfacing (15/20mm) _____ OTHER: _____ _____	<b>Medial Tibial Plateau</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ OTHER: _____ <hr/> <b>Medial Meniscus</b> Partial Meniscectomy _____ Meniscal Repair _____ Meniscal Allograft _____ OTHER: _____ _____	
<b>Lateral Compartment Surgical History:</b>		<input type="checkbox"/> <b>No Prior Procedure</b>
<b>Lateral Femoral Condyle</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ Osteochondral Autograft _____ Osteochondral Allograft _____ Cell Based Cartilage Procedures _____ Focal HemiCAP Resurfacing (15/20mm) _____ OTHER: _____ _____	<b>Lateral Tibial Plateau</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ OTHER: _____ <hr/> <b>Lateral Meniscus</b> Partial Meniscectomy _____ Meniscal Repair _____ Meniscal Allograft _____ OTHER: _____ _____	
<b>Patellofemoral Joint Surgical History:</b>		<input type="checkbox"/> <b>No Prior Procedure</b>
<b>Patella</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ Osteochondral Autograft _____ Osteochondral Allograft _____ Cell Based Cartilage Procedures _____ OTHER: _____ _____	<b>Trochlea</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ Osteochondral Autograft _____ Osteochondral Allograft _____ Cell Based Cartilage Procedures _____ OTHER: _____ _____	
<b>Ligament, Tendon, Capsular, Realignment Procedures, etc.:</b>		<input type="checkbox"/> <b>No Prior Procedure</b>
ACL Reconstruction _____ PCL Reconstruction _____ MCL Reconstruction _____ LCL Reconstruction _____ Posterolateral Reconstruction _____ OTHER: _____ _____	Patella Tendon Repair _____ Quadriceps Tendon Repair _____ PF Medial Imbrication _____ PF Lateral Release _____ PF Tibial Tubercle Transfer _____ Trochleoplasty _____ Patellectomy _____ High Tibial Osteotomy _____	

5. Surgical History. *Please indicate the number of previous procedures in the uninvolved knee:*

<b>Medial Compartment Surgical History:</b>		<input type="checkbox"/> <b>No Prior Procedure</b>
<b>Medial Femoral Condyle</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ Osteochondral Autograft _____ Osteochondral Allograft _____ Cell Based Cartilage Procedures _____ Focal HemiCAP Resurfacing (15/20mm) _____ OTHER: _____ _____	<b>Medial Tibial Plateau</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ OTHER: _____ _____	<b>Medial Meniscus</b> Partial Meniscectomy _____ Meniscal Repair _____ Meniscal Allograft _____ OTHER: _____ _____
<b>Lateral Compartment Surgical History:</b>		<input type="checkbox"/> <b>No Prior Procedure</b>
<b>Lateral Femoral Condyle</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ Osteochondral Autograft _____ Osteochondral Allograft _____ Cell Based Cartilage Procedures _____ Focal HemiCAP Resurfacing (15/20mm) _____ OTHER: _____ _____	<b>Lateral Tibial Plateau</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ OTHER: _____ _____	<b>Lateral Meniscus</b> Partial Meniscectomy _____ Meniscal Repair _____ Meniscal Allograft _____ OTHER: _____ _____
<b>Patellofemoral Joint Surgical History:</b>		<input type="checkbox"/> <b>No Prior Procedure</b>
<b>Patella</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ Osteochondral Autograft _____ Osteochondral Allograft _____ Cell Based Cartilage Procedures _____ OTHER: _____ _____	<b>Trochlea</b> Debridement _____ Microfracture _____ Abrasion Arthroplasty/Chondroplasty/Drilling _____ Thermal Tissue Ablation _____ Osteochondral Autograft _____ Osteochondral Allograft _____ Cell Based Cartilage Procedures _____ OTHER: _____ _____	
<b>Ligament, Tendon, Capsular, Realignment Procedures, etc.:</b>		<input type="checkbox"/> <b>No Prior Procedure</b>
ACL Reconstruction _____ PCL Reconstruction _____ MCL Reconstruction _____ LCL Reconstruction _____ Posterolateral Reconstruction _____ OTHER: _____ _____	Patella Tendon Repair _____ Quadriceps Tendon Repair _____ PF Medial Imbrication _____ PF Lateral Release _____ PF Tibial Tubercle Transfer _____ Trochleoplasty _____ Patellectomy _____ High Tibial Osteotomy _____	

**A. FOLLOW-UP KNEE EXAMINATION**

**1. Symptoms of the Involved Knee** (*"Involved Knee" refers to the operative knee*)

- Pain:  None  Mild  Moderate  Severe  Extreme  
 Swelling:  Yes  No  
 Locking:  Yes  No  
 Giving-way:  Yes  No

**B. POSTOPERATIVE MILESTONES**

1. Length of Hospitalization (admission to discharge): \_\_\_\_\_ **Hours**  
 2. Time to Ambulation with Support (Crutches etc): \_\_\_\_\_ **Hours**  
 3. Time to Ambulation without Support (Crutches etc.): \_\_\_\_\_ **Days**  
 3. Time to reach full range of motion (ROM): \_\_\_\_\_ **Days**  
 4. Length of Postoperative Rehabilitation \_\_\_\_\_ **Weeks**

Please explain what this rehabilitation entailed and its duration (Physiotherapy, Biokinetics etc.): \_\_\_\_\_  
 \_\_\_\_\_

5. Time to Return to Work \_\_\_\_\_ **Weeks**  
 NA - Patient not working prior to surgery  
 6. Time to Return to Sports \_\_\_\_\_ **Months**  
 NA - Patient was not seeking to return to sport

**G. ADDITIONAL COMMENTS**

\_\_\_\_\_  
 \_\_\_\_\_

**Patient Signature:** \_\_\_\_\_ **Date:** \_\_\_\_\_

**Investigator Signature:** \_\_\_\_\_ **Date:** \_\_\_\_\_

**Thank you for completing all the questions in this questionnaire.**

## APPENDIX C: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PARQ)

University of Cape Town  
Sport Science Orthopaedic Centre

**Physical Activity Readiness Questionnaire (PAR-Q)**

Name			Date
DOB:	Age:	Home Phone:	Work Phone:

Regular exercise is associated with many health benefits, yet any change of activity may increase the risk of injury. This questionnaire identifies whether you are at risk.

Please read each question carefully and answer every question honestly:

Yes	No	1) Has a physician ever said you have a heart condition and you should only do physical activity recommended by a physician?
Yes	No	2) When you do physical activity, do you feel pain in your chest?
Yes	No	3) When you were not doing physical activity, have you had chest pain in the past month?
Yes	No	4) Do you ever lose consciousness or do you lose your balance because of dizziness?
Yes	No	5) Do you have a joint or bone problem that may be made worse by a change in your physical activity?
Yes	No	6) Is a physician currently prescribing medications for your blood pressure or heart condition?
Yes	No	7) Are you pregnant?
Yes	No	8) Do you have insulin dependent diabetes?
Yes	No	9) Are you 69 years of age or older?
Yes	No	10) Do you know of any other reason you should not exercise or increase your physical activity?

If you answered **yes** to any of the above questions, you need to consult your doctor **BEFORE** you can participate in this experiment. If you honestly answered **no** to all questions, you can be reasonably positive that you are not at an increase risk by participating in this study. If your health changes so you then answer **yes** to any of the above questions, seek guidance from a physician.

Participant Signature	Date
-----------------------	------

**Thank you for completing all the questions in this questionnaire.**

## APPENDIX D: KNEE INJURY AND OSTEOARTHRITIS OUTCOME SCORE (KOOS)

University of Cape Town  
Sport Science Orthopaedic Centre



### KNEE INJURY AND OSTEOARTHRITIS OUTCOME SCORE (KOOS)

#### INSTRUCTIONS:

This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to do your usual activities. Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

#### SYMPTOMS:

These questions should be answered thinking of your knee symptoms during the **last week**.

S1. Do you have swelling in your knee?

Never	Rarely	Sometime	Often	Always
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

S2. Do you feel grinding; hear clicking or any other type of noise when your knee moves?

Never	Rarely	Sometime	Often	Always
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

S3. Does your knee catch or hang up when moving?

Never	Rarely	Sometime	Often	Always
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

S4. Can you straighten your knee fully?

Always	Often	Sometime	Rarely	Never
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

S5. Can you bend your knee fully?

Always	Often	Sometime	Rarely	Never
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**STIFFNESS:**

The following questions concern the amount of joint stiffness you have experienced during the **last week** in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

S6. How severe is your knee joint stiffness after first wakening in the morning?

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

S7. How severe is your knee stiffness after sitting, lying or resting **later in the day**?

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**PAIN:**

P1. How often do you experience knee pain?

Never	Monthly	Weekly	Daily	Always
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

What amount of knee pain have you experienced the **last week** during the following activities?

P2. Twisting/pivoting on your knee

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P3. Straightening knee fully

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P4. Bending knee fully

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P5. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P6. Going up or down stairs

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P7. At night while in bed

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P8. Sitting or lying

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

P9. Standing upright

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

#### FUNCTION, DAILY LIVING:

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A2. Ascending stairs

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A3. Rising from sitting

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A4. Standing

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A5. Bending to floor/pick up an object

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A6. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A7. Getting in/out of car

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A8. Going shopping

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A9. Putting on socks/stockings

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A10. Rising from bed

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A11. Taking off socks/stockings

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A12. Lying in bed (turning over, maintaining knee position)

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A13. Getting in/out of bath

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A14. Sitting

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A15. Getting on/off toilet

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A16. Heavy domestic duties: moving heavy boxes, scrubbing floors, etc.

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

A17. Light domestic duties (cooking, dusting, etc.)

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

#### FUNCTION, SPORTS AND RECREATIONAL ACTIVITIES:

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your knee.

SP1. Squatting

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SP2. Running

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SP3. Jumping

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SP4. Twisting/pivoting on your injured knee

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SP5. Kneeling

None	Mild	Moderate	Severe	Extreme
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**QUALITY OF LIFE:**

Q1. How often are you aware of your knee problem?

Never                      Monthly                      Weekly                      Daily                      Constantly  
                                                                                                                                                       

Q2. Have you modified your life style to avoid potentially damaging activities to your knee?

Not at all                      Mildly                      Moderately                      Severely                      Totally  
                                                                                                                                                       

Q3. How much are you troubled with lack of confidence in your knee?

Not at all                      Mildly                      Moderately                      Severely                      Extremely  
                                                                                                                                                       

Q4. In general, how much difficulty do you have with your knee?

Not at all                      Mild                      Moderate                      Severe                      Extreme  
                                                                                                                                                       

**Thank you for completing all the questions in this questionnaire.**

## APPENDIX E: SF-36 HEALTH SURVEY

## SF-36® Health Survey Scoring Demonstration

This survey asks for your views about your health. This information will help you keep track of how you feel and how well you are able to do your usual activities.

Answer every question by selecting the answer as indicated. If you are unsure about how to answer a question, please give the best answer you can.

---

1. In general, would you say your health is:

Excellent	Very good	Good	Fair	Poor
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

---

2. Compared to one year ago, how would you rate your health in general now?

Much better now than one year ago	Somewhat better now than one year ago	About the same as one year ago	Somewhat worse now than one year ago	Much worse now than one year ago
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

---

3. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

	Yes, limited a lot	Yes, limited a little	No, not limited at all
a <u>Vigorous activities</u> , such as running, lifting heavy objects, participating in strenuous sports	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b <u>Moderate activities</u> , such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c Lifting or carrying groceries	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d Climbing <u>several</u> flights of stairs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e Climbing <u>one</u> flight of stairs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f Bending, kneeling, or stooping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g Walking <u>more than a mile</u>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h Walking <u>several blocks</u>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
i Walking <u>one block</u>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
j Bathing or dressing yourself	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

---

4. During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of your physical health**?

- |   | Yes                      | No                       |
|---|--------------------------|--------------------------|
| a Cut down on the <u>amount of time</u> you spent on work or other activities                       | <input type="checkbox"/> | <input type="checkbox"/> |
| b <u>Accomplished less</u> than you would like  | <input type="checkbox"/> | <input type="checkbox"/> |
| c Were limited in the <u>kind</u> of work or other activities                                       | <input type="checkbox"/> | <input type="checkbox"/> |
| d Had <u>difficulty</u> performing the work or other activities (for example, it took extra effort) | <input type="checkbox"/> | <input type="checkbox"/> |

---

5. During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of any emotional problems** (such as feeling depressed or anxious)?

- |   | Yes                      | No                       |
|---|--------------------------|--------------------------|
| a Cut down on the <u>amount of time</u> you spent on work or other activities | <input type="checkbox"/> | <input type="checkbox"/> |
| b <u>Accomplished less</u> than you would like                                | <input type="checkbox"/> | <input type="checkbox"/> |
| c Did work or other activities <u>less carefully than usual</u>               | <input type="checkbox"/> | <input type="checkbox"/> |

---

6. During the **past 4 weeks**, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

- | Not at all               | Slightly                 | Moderately               | Quite a bit              | Extremely                |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

---

7. How much **bodily pain** have you had during the **past 4 weeks**?

- | None                     | Very mild                | Mild                     | Moderate                 | Severe                   | Very severe              |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

---

8. During the **past 4 weeks**, how much did **pain** interfere with your normal work (including both work outside the home and housework)?

- | Not at all               | A little bit             | Moderately               | Quite a bit              | Extremely                |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
-

9. These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling.

How much of the time during the past 4 weeks...

	All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	None of the time
a Did you feel full of pep?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b Have you been a very nervous person?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c Have you felt so down in the dumps that nothing could cheer you up?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d Have you felt calm and peaceful?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
e Did you have a lot of energy?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
f Have you felt downhearted and blue?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
g Did you feel worn out?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
h Have you been a happy person?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
i Did you feel tired?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

10. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?

All of the time	Most of the time	Some of the time	A little of the time	None of the time
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

11. How TRUE or FALSE is each of the following statements for you?

	Definitely true	Mostly true	Don't know	Mostly false	Definitely false
a I seem to get sick a little easier than other people	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b I am as healthy as anybody I know	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c I expect my health to get worse	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d My health is excellent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

*Thank you for completing these questions!*

<a href="#">Score the survey</a>	<a href="#">Reset the survey form</a>
----------------------------------	---------------------------------------

## APPENDIX F: TEGNER SCALE

University of Cape Town  
Sport Science Orthopaedic Centre

**TEGNER ACTIVITY LEVEL SCALE**

Current Level: \_\_\_\_\_

LEVEL 10	Competitive Sports: Soccer- National And International Elite
LEVEL 9	Competitive Sports: Soccer (Lower Divisions), Ice Hockey, Wrestling, Gymnastics
LEVEL 8	Competitive Sports: Squash, Badminton, Athletics (Jumping, Etc.), Downhill Skiing
LEVEL 7	Competitive Sports: Tennis, Athletics (Running, Etc.), Motocross, Speedway, Handball, Basketball Recreational Sports: Soccer, Bandy And Ice Hockey, Squash, Athletics (Jumping, Etc.), Cross-Country Track Findings Both Recreational and Competitive
LEVEL 6	Recreational Sports: Tennis and Badminton, Handball, Basketball, Downhill Skiing, Jogging at Least 5 Days a Week
LEVEL 5	Work: Heavy Labour (E.G. Building Or Forestry) Competitive Sports: Cycling, Cross- Country Skiing Recreation Sports: Jogging on Uneven Ground at Least Twice a Week
LEVEL 4	Work: Moderately Heavy Labour (E.G. Truck Driving, Heavy Domestic Work) Recreational Sports: Cycling, Cross- Country Skiing, Jogging, on Even Ground at Least Twice Weekly
LEVEL 3	Work: Light Labour (E.G. Nursing) Competitive and Recreational Sports: Swimming, Walking in Forest is Possible
LEVEL 2	Work: Light Labour, Walking on Uneven Ground is Possible, But Impossible to Walk in Forest
LEVEL 1	Work: Sedentary Work, Walking on Even Ground is Possible
LEVEL 0	Sick Leave or Disability Pension Because of Knee Problems

Patient Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Investigator Signature: \_\_\_\_\_

Date: \_\_\_\_\_

**APPENDIX G: CYCLE ERGOMETRY PROTOCOL**

<b>Eccentric Group (ECC)</b>		<b>Concentric Group (CON)</b>	
Direction of Grucox Bike: Reverse		Direction of Grucox Bike: Reverse	
2 min	Continuous Passive Movement	2 min	Continuous Passive Movement
8 min	Eccentric work	8 min	Concentric work
Direction of Grucox Bike: Forward		Direction of Grucox Bike: Forward	
1 min	Continuous Passive Movement	1 min	Continuous Passive Movement
8 min	Eccentric work	8 min	Concentric work
1 min	Cool down	1 min	Cool down

## APPENDIX H: TESTING SHEET

TESTING TEMPLATE

<b>Participant Name:</b>	<b>Number:</b>

VICON

<b>Name</b>	<b>Description</b>	<b>Measurement</b>
<b>Body Mass</b>	Patient mass	_____ Kg
<b>Height</b>	Patient Height	_____ mm
<b>Left Leg Length</b>	Full leg length, measured between the ASIS marker and the medial malleolus, via the knee joint.	_____ mm
<b>Left Knee Width</b>	The medio-lateral width of the knee across the line of the knee axis.	_____ mm
<b>Left Ankle Width</b>	The medio-lateral distance across the malleoli.	_____ mm
<b>Right Leg Length</b>	Full leg length, measured between the ASIS marker and the medial malleolus, via the knee joint.	_____ mm
<b>Right Knee Width</b>	The medio-lateral width of the knee across the line of the knee axis.	_____ mm
<b>Right Ankle Width</b>	The medio-lateral distance across the malleoli.	_____ mm

**LEAN LEG VOLUME**

Name	Description	Measurement	
		Left	Right
<b>Thigh Skinfold</b>	Mid-point on the anterior surface of the thigh with the fold parallel to the long axis of the thigh. Subjects weight should be on the other leg so that the measured knee joint in at an angle of about 120°	_____mm	_____mm
<b>Sub-gluteal Girth</b>	Measured 1cm below the gluteal fold. Weight must be distributed evenly on both legs	_____cm	_____cm
<b>Mid-thigh Girth</b>	Measured at the level at which the skinfold was taken. Weight must be distributed evenly on both legs	_____cm	_____cm
<b>Above Knee Girth</b>	Measured 1cm above the superior border of the patella.	_____cm	_____cm
<b>Sub-gluteal-Above Knee Length</b>	Measured as the distance between the sub-gluteal girth and the above knee girth measurements	_____cm	_____cm

**6 MINUTE WALK TEST**

Name	Description	Measurement
<b>Heart Rate Before</b>		_____bpm
<b>Laps covered</b>		_____mm
<b>Distance covered</b>		_____mm
<b>Heart Rate After</b>		_____bpm

**BIODEX**

Name	Description	Measurement	
		Left	Right
<b>Chair Foot Pedal</b>	Chair Travelator- fore and aft	_____mm	_____mm
<b>Chair height</b>	Up and Down buttons located behind the chair	_____mm	_____mm
<b>Chair Base</b>	The length of the seat pan	_____mm	_____mm
<b>Attachment Length</b>	The length of the knee attachment	_____mm	_____mm

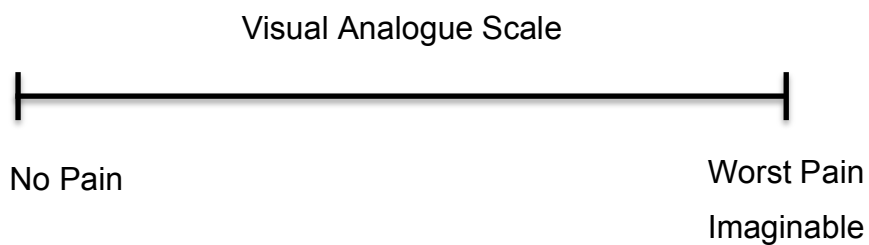
**APPENDIX I: THE BORG RATING OF PERCEIVED EXERTION SCALE**

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

**APPENDIX J: PRESCRIBED INTENSITIES**

<b>Training week</b>	<b>Exercise session</b>	<b>Intensity (RPE)</b>	<b>Duration (minutes)</b>
1	1	Familiarisation	20
	2	7 (Extremely light)	20
	3	9 (Very light)	20
2	4	9 (Very light)	20
	5 – 6	11 (Light)	20
3-4	7-12	13 (Somewhat hard)	20
5-6	13 - 18	13 (Somewhat hard)	20
7-8	19 - 24	15 (Hard)	20

**APPENDIX K: PAIN VISUAL ANALOGUE SCALE**



## APPENDIX L: GRUCOX TESTING SHEET

University of Cape Town  
Sport Science Orthopaedic Centre



### GRUCOX TESTING SHEET

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Session: \_\_\_\_\_

**Bike Setup:**

Weight: \_\_\_\_\_

Speed: \_\_\_\_\_

Torque: \_\_\_\_\_

Time: Minutes	VAS: Visual analogue scale	HR: Heart rate	RPE: Rating of Perceived Exertion
20			
18			
14			
10			
9			
5			
1			
0			

**Watts**

**Concentric**

**Eccentric**

**Left**

Ave: \_\_\_\_\_ Max: \_\_\_\_\_ Ave: \_\_\_\_\_ Max: \_\_\_\_\_

**Right**

Ave: \_\_\_\_\_ Max: \_\_\_\_\_ Ave: \_\_\_\_\_ Max: \_\_\_\_\_